EELLS & VAN DERVOORT

The Transmission of Pressure through Sand

Civil Engineering

B. S.

1911

UNIV OF
ILLINOIS
LIBRARY

UNIVERSITY OF ILLINOIS
LIBRARY

Class 1911 Book Ee5 Volume

THE TRANSMISSION OF PRESSURE THROUGH SAND

BY

WILLARD CLARK EELLS

AND

JAMESON VAN DERVOORT

THESIS

FOR THE

DEGREE OF

BACHELOR OF SCIENCE

IN

CIVIL ENGINEERING

IN THE

COLLEGE OF ENGINEERING

UNIVERSITY OF ILLINOIS

1911

1911
Ee5

UNIVERSITY OF ILLINOIS.

COLLEGE OF ENGINEERING.

June 1, 1911.

This is to certify that the thesis prepared in the Department of Theoretical and Applied Mechanics by WILLARD CLARKE EELLS and JAMESON VAN DERVOORT entitled The Transmission of Pressure through Sand is approved by me as fulfilling this part of the requirements for the degree of Bachelor of Science in Civil Engineering.

M. L. Enger
Instructor in Charge.

Approved:

A. N. Talbot
Professor of Municipal and Sanitary Engineering.
In Charge of Theoretical and Applied Mechanics.

Approved:

Ira O. Baker.
Professor of Civil Engineering.

197597

Digitized by the Internet Archive
in 2013

http://archive.org/details/transmissionofpr00eell

1911
EeS

THE TRANSMISSION OF PRESSURE THROUGH SAND.

I. Introduction.

The amount of concentrated load which can be transmitted through a bed of sand and the direction of the lines of pressure transferring this load to the supporting surface beneath, are subjects about which little is known. Safe working loads have been determined by actual experience, and it is generally assumed that the pressure is transferred to a larger area of the supporting surface than the area of sand loaded, but practically no experiments have been carried on to determine what actually happens when a concentrated load is applied to a bed of sand not confined within small limits. It is the purpose of the writers to build apparatus by means of which data can be obtained to determine, (a) the relation between the maximum unit load which can be sustained and the depth of sand, (b) the variation of maximum unit load sustained with the area of surface loaded, and (c) the variation of the intensity of pressure with the depth of sand and distance from the center of concentration of the load.

This thesis is intended to carry farther the work of Kingsley Abner Burnell, Class of 1910, who stated that his thesis was "more for the determination of the best method of procedure than as a complete solution of the problem." For this reason a large percentage of the allotted time was devoted to the design and construction of apparatus which would sustain and accurately measure loads up to fifty thousand pounds. The apparatus, as constructed, will undoubtedly be of value in determining loads which can be sustained by crushed rock,

UIUC

gravel, or earth, should such data be desired.

The subject will be discussed under the following heads: II. Description of Apparatus and Methods used, III. Experimental Data and Discussion, and IV. Conclusion.

II. Description of Apparatus and Methods Used.

To support the sand a floor or base (Fig. 1-A) 9 feet long by 8 1/2 feet wide by 16 inches thick was constructed of concrete. As this base was designed to carry 50,000 pounds acting as a slab, it was heavily reinforced with longitudinal rods and stirrups. To prevent breakage above the rectangular open space (B), the purpose of which will be shown later, short transverse reinforcing rods were placed above this channel and extended into the solid masonry. Planks (C) around the outer edge of the base kept the sand from flowing off. Near the ends of the base, four 1 inch rods (D) 8 1/2 feet long were securely fastened in pairs to two steel plates imbedded as near the bottom of the concrete as possible. A 20 inch I-beam (E) was suspended between the rods and held down by two heavy plates (F) two inches thick through which the rods were passed. The upper ends of the rods were threaded and nuts screwed on to bear against the upper sides of the plates. A 40 ton hydraulic jack (G) was used to furnish the pressure. The upward thrust of the jack was taken by the large I-beam and transferred to the heavy base through the four 1 inch rods. When no load was on the large I-beam, it was held suspended to the floor above by stirrups (H) consisting of small iron rods and wooden cross-pieces.

Two methods for measuring the pressure transferred through the sand were used, with the idea of furnishing a check on the readings taken. The first of these is described as follows: A rectangular opening (B) 6 inches by 6 inches by 5 feet 8 inches was left in the base by placing wooden forms during construction, which were removed later. In the bottom of the opening was imbedded a steel block (I) to

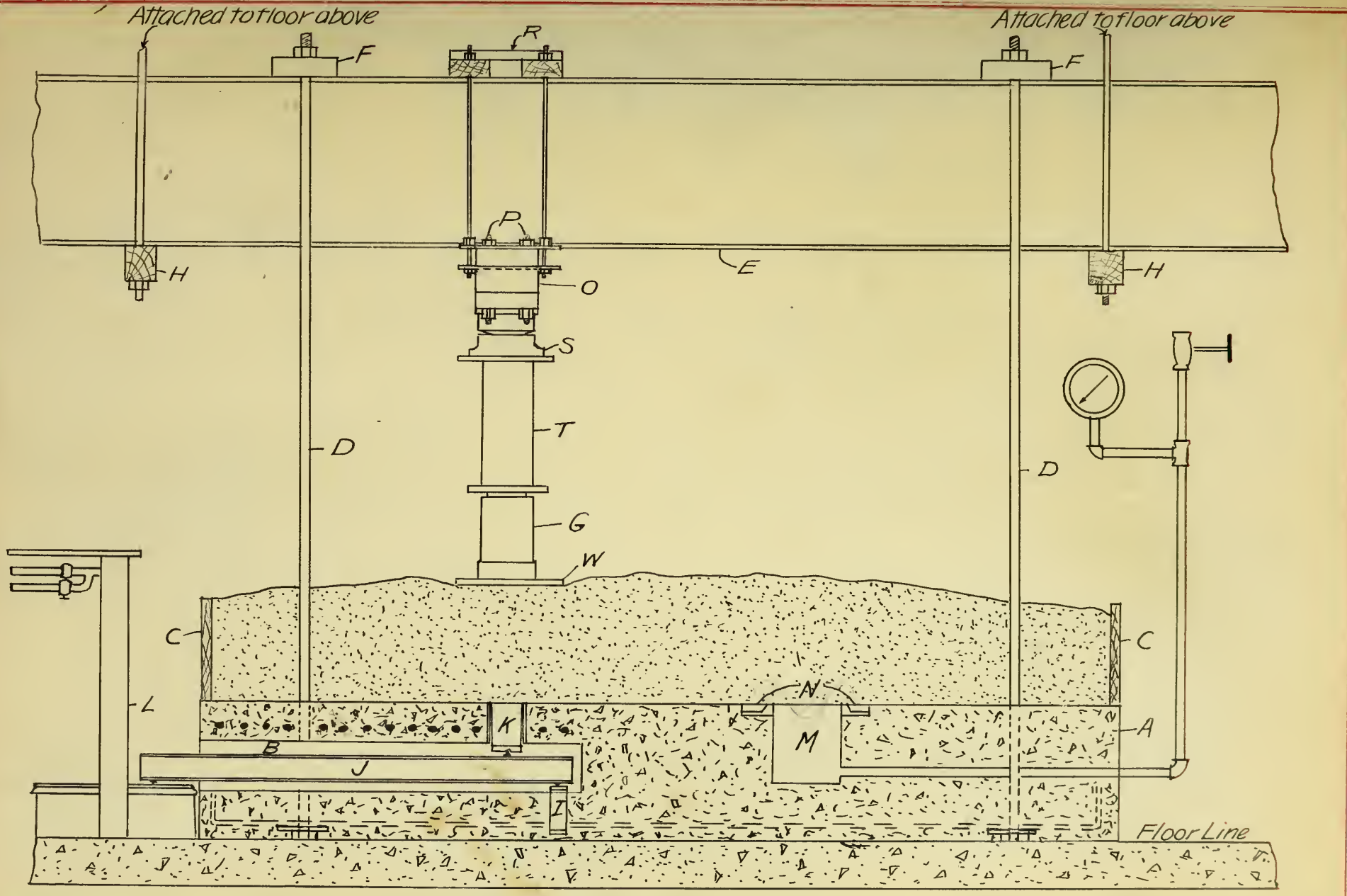

Attached to floor above
Attached to floor above
F
F
R
P
H
H
E
O
S
T
D
D
G
W
C
C
L
K
N
M
A
B
J
I
Floor Line

Fig 1

support a knife edge on a 5 inch I-beam (J) used as a lever arm. About 6 inches from the middle of this block and 5 feet from the edge of the base a circular hole 4 1/8 inches in diameter was formed by a short length of iron pipe. This hole was made to connect the rectangular opening with the upper face of the concrete base. A knife edge was fastened to the I-beam lever arm (J) directly under the center of the hole. A wooden plug (K) 4 inches in diameter of the top was turned with a slight taper to prevent binding and cut to the proper length to fit into the hole with its upper surface just flush with the surrounding concrete surface. A steel plate with a V-shaped slot in which to rest the knife edge beneath, was screwed to the bottom of the plug. Three feet 6 inches from the center of the plug a third knife edge was fastened to the I-beam lever arm to rest upon a set of scales (L) placed beside the base at the end of the rectangular opening. The scales were somewhat dilapidated but, when tested, proved to be quite accurate. They were graduated to read half-pounds but quarter-pounds could be read with a little care. The pressure transferred through the sand to the plug was carried by it to the lever arm and indicated by the readings on the scale.

To better determine the ratio of load on the plug to that on the scales the lever arm was tested upon a machine in the laboratory. The lever arm had been roughly constructed for a ratio of scale readings to load on plug of 1:8 but the test showed this ratio to be 1:8.09. The latter value has been used in reducing readings.

To prevent sand from entering between the plug and surrounding iron pipe, a piece of sheet rubber was placed to cover the plug and extend over a small part of the surrounding concrete.

The second method of measuring pressure transferred through the sand was by means of water pressure. An 8 inch iron cylinder (M), closed at the bottom, was placed in the concrete 5 feet from the wooden plug and about the same distance from the end of the base. A surrounding flange with a beveled edge was screwed to the top of the cylinder. A diaphragm of Number 16 packing rubber was made to cover the top of the cylinder and pass over the beveled edge of the flange. To form a perfectly water-tight joint a flat collar (N), also beveled, was made to cover the diaphragm and flange and be bolted down in such a manner that the rubber was held tightly between the beveled edges. The cylinder was connected to a pressure gauge by means of a 3/4 inch pipe leading through the concrete and passing outside the base. The gauge was attached below the top of the vertical pipe to allow the escape of air, for which purpose a valve was used at the upper end of the pipe.

The method of filling the cylinder and pipe was as follows: The cylinder was first filled to the brim with water. To make sure no air remained, a continuous flow was kept up through the pipe and out through the cylinder. When water was flowing freely over the edges of the cylinder, it was covered with the rubber diaphragm with such care as to prevent any trapping of air beneath, then the collar was put into place and bolted down. The remainder of the pipe was then filled and the valve closed. Pressure applied through the sand above the diaphragm was carried to the gauge by the water column and read in pounds per square inch.

This apparatus when tested was found to be very sensitive under small loads, but when the pressure on the gauge registered 70 pounds per square inch, the rubber diaphragm burst. As it would be necessary to

read pressures higher than 70 pounds per square inch, the diaphragm was not repaired. A stronger one could have been designed had time permitted, but it was deemed better to take all the data with the plug and lever-arm apparatus than to spend valuable time in experimenting with the diaphragm when results were so uncertain. Accordingly, all the data were taken with the stronger apparatus.

To measure the total load sustained by the sand a rather unique device was designed and built. It was thought that a pressure gauge on the hydraulic jack, which is a method in common use for determining loads, would not give accurate enough results because of the friction in the jack and the difficulty in getting a pressure gauge which would be required to read accurately pressures as high as 5000 pounds per square inch and as low as 20 or 25 pounds per square inch. Accordingly, the following method was used. A spring (O) was constructed of 2 steel plates, (See photograph, page 12), free to bend at the middle and held apart at the ends by blocks of steel, the whole being bolted tightly together. The spring was built to withstand a concentrated load at the center of 50,000 pounds with a total deflection of about 0.24 inches, the idea being to calibrate the spring and measure loads by means of the deflections. It was built of high grade nickel steel. The plates were made 7 1/2 inches wide by two inches thick, with a distance of 28 inches center to center of bolts through the supporting blocks. A clear distance of three inches separated the inner faces of the two plates and an Ames dial reading directly to 0.001 inches was placed between them to measure the deflection under the load. Knife edges 1/2 inches wide were placed transversely at the middle of the spring to take the load from the jack and transfer it to the I-beam above. One knife edge

was placed exactly at the middle on the under side, and, to give a secure bearing next the I-beam, two were used on that side. They were spaced 4 inches apart and equidistant from the middle of the spring. The whole was swung by 4 small rods passing through flat iron pieces which clamped the spring, and extending through a wooden framework resting on the upper flange of the I-beam. Before a load was applied the spring was clamped into firm contact with the I-beam. When necessary to move the spring the rods were loosened and the wooden framework, with the suspended spring, pushed along the I-beam.

The spring was designed from the formulae $S = \frac{Mc}{I} = \frac{Plc}{I}$ and $f = \frac{Pl^3}{48EI}$ for a simple beam with concentrated load at the middle. Allowing a deflection f at the center of 0.15 inches for each plate; taking the load P as 50,000 pounds, the allowable flexural stress as 70,000 pounds per square inch for high grade steel, and c equal to 1 inch, the expression $l = 27.5$ inches is obtained. For a plate 7 1/2 inches wide, S = 70,000 pounds per square inch with a deflection f in each plate of 0.15 inches. For reasons to be explained later, the bolts through the ends were tightened and the spring no longer acted as a simple beam. Considering it as a fixed beam would reduce the stress to 1/2 the simple beam stress or 35,000 pounds per square inch, and the deflection to 1/4 the amount originally calculated or 0.04 inches in each plate. In testing the spring the actual deflection corresponding to a load of 50,000 pounds was found to be 0.24 inches which goes to show that the plates acted neither wholly as simple beams nor wholly as fixed beams. The actual stress must, therefore, have been between 35,000 pounds per square inch and 70,000 pounds per square inch. Judging from the deflections, it probable slightly exceeded 60,000 pounds per square inch under the maximum

loading.

The spring was calibrated on a testing machine in the laboratory. The loads were read to the nearest 10 pounds and the deflections estimated to the nearest 0.0001 inches. As the tightness of the bolts greatly affected the amount of deflection, the spring was tested with bolts slightly tightened, with bolts loose, with bolts tightened upon rubber washers, and with bolts tightened snugly without washers. The last named condition was found to give the most uniform results, and it was decided to use the spring in that manner. The load was applied and taken off a total of twenty times to reduce the chances of error from any initial set in the steel. The separate determinations of deflections and corresponding loads checked very closely. With care the loads could be determined from the deflection to the nearest thirty or forty pounds.

As the use of the spring weighing device was more or less an experiment, its behavior was noticed with particular care. The Ames dial was set exactly at zero with no load on the spring, and each time a load was applied and removed the position of the needle was noticed. Invariably the needle returned exactly to zero, and, although the spring was loaded over one hundred times, it failed to show any signs of initial set, or change in any manner. Its use was a very material benefit in obtaining the data of this thesis. As mentioned before, it read heavy and light loads accurately, and the readings were not affected by friction in the jack or errors to which Bourdon pressure-gauges are liable. It was easily moved along the large I-beam into a new position.

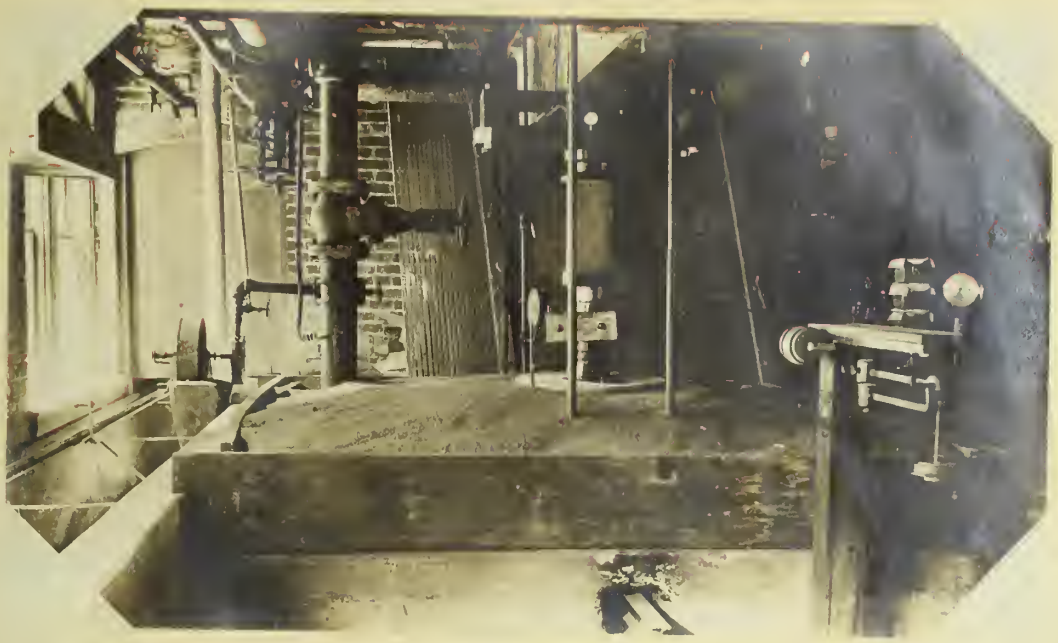
The load was applied to the sand through a steel plate (W).

The hydraulic jack (G) rested directly upon this plate, and above the jacks was a wooden post or column (T) of yellow pine 6 inches by 6 inches in section, which transferred the upper pressure to the steel spring. Between the top of the wooden column and the lower knife edge of the spring, was placed a bearing-block (S). This bearing-block had been used in calibrating the spring and was used during the experiments to distribute the load uniformly along the knife edge.

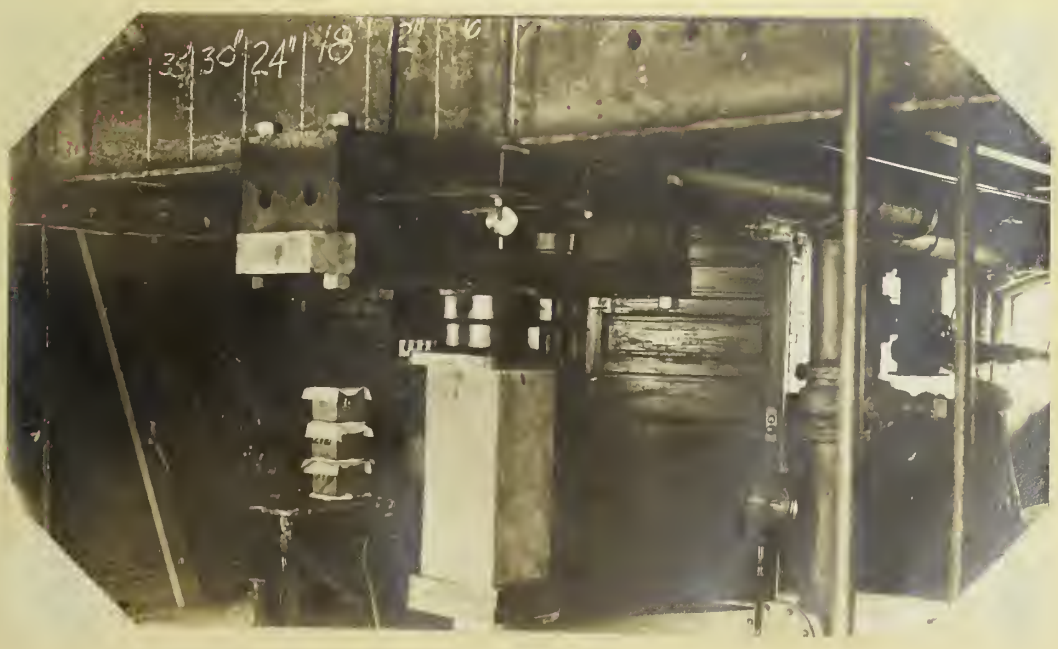
To carry out the purposes of this thesis as stated in the introduction, two separate sets of data were taken. The first set was taken to determine the maximum unit load a plate could carry for various depths of sand and sizes of plate as follows: the plate was first loaded over a depth of sand of 24 inches, and, as the plate sank into the sand which flowed out from under it, simultaneous readings of the depth of sand and total load were taken. In each case the plate was pushed down until the limiting load for which the spring was built, was nearly reached. The sand was not allowed to flow in and cover the top of the plate, but was kept cleared away even with its upper surface. The depth of sand was measured upon a small iron rod graduated in inches, thrust down to the upper surface of the concrete base. A scale graduated to tenths of inches was used in connection with the rod and the depth of sand read to the nearest 0.1 inch. As the total distance the plate travelled was from 12 to 18 inches these readings were deemed sufficiently accurate. Plates 6 1/2, 15 1/2, and 21 inches in diameter were loaded as described. The second set of data was taken to determine the intensity of pressure transferred through the sand to different points on the supporting surface. The 15 1/2 inch plate was the only one used in this determination. Readings were taken for depths of sand

of 6, 12, and 18 inches, and distances of 0, 3, 6, 12, and 18 inches between the center of applied pressure and the center line of the plug. The method used was as follows: the plate was loaded directly over the plug with a depth of packed sand of 6 inches and scale and deflectometer readings taken as the load was applied and released by increments. The spring, jack, and plate were then moved to a distance of 3 inches from the center line of the plug, and, with the sand still 6 inches deep, another set of readings taken. In this manner the spring, jack, and plate were moved away from the plug by increments of 3 and 6 inches until no pressure reached the plug, while the depth of sand remained the same as before. A depth of sand of 12 inches, then 18 inches, was loaded and the previous process of moving the center of pressure away from the center of the plug by increments of 3 and 6 inches repeated. In placing the plate care was taken to get it into exactly the proper position, to level it perfectly upon the sand, and keep it as nearly level as possible during the loading. Before any readings were taken, the sand was packed thoroughly by applying a load to the plate and sinking it 2 or 3 inches. For example, when readings were taken for 12 inches of sand, the plate was started at about 15 inches, then forced down to a depth of slightly over 12 inches, when the load was released and applied several times to obtain readings. During this time the plate sank enough to give an average depth of sand of 12.0 inches.

The sand used in the experiments was very dry, smooth torpedo sand from Attica, Indiana. It was very dirty and contained much dust and fine material.



PHOTOGRAPH OF APPARATUS



PHOTOGRAPH OF STEEL SPRING

III. Experimental Data and Discussion.

With the exceptions of tables 1 and 5 the values in the following tables are averages of from three to six tests. The values given in table 5 are averaged from twelve to fourteen tests.

In all tables and plates the term "load on " indicates an increasing load, and the term "load off" indicates a decreasing load.

Table 1 contains data for the calibration of the steel spring. The values are averages of ten tests which checked closely.

The data in tables 2, 3, and 4 were taken for the purpose of determining the variation of maximum unit load sustained with depth of sand, and the variation of maximum unit load sustained with the area of surface loaded. These purposes were stated in the Introduction and referred to in the Description of Apparatus and Methods used. Column 3 was obtained by taking the load corresponding to the deflections of the steel spring shown in column 1 from the calibration curve shown in plate I. Column 4 was obtained by dividing the total load in pounds on the plate by the area of the plate in square inches.

Tables 5 to 16, inclusive, contain data taken for the purpose of determining the variation of intensity of pressure with the depth of sand and with the distance from the center of the applied pressure. Column 2 was obtained from column 1 and plate I. Column 4 was obtained by subtracting the initial scale reading for zero load on the plate from the values in column 3, and multiplying by 8.09.

Column 5 was obtained by dividing the total load on the plate in column 2 by 144, which is the area of the 15 1/2 inch plate used in

obtaining all the data in tables 5 to 16. Column 6 was obtained by dividing the values in column 4 by 12.56, which is the area of the 4 inch wooden plug. Column 7 was obtained by dividing the values in column 6 by the corresponding values in column 5.

Plate 1 is the calibration curve for the steel spring. The curve shows that for a given deflection a slightly smaller load was needed for load off than for load on. This was probably due to the slowness of the steel to exert its full resisting power when the deflection was decreasing. Because of its uniformity the curve emphasizes the claims made for the good behavior of the steel spring.

Plate 2 was plotted to show graphically the variation of maximum unit load sustained with depth of sand and with area loaded. Because the sand had to be heaped up in the form of a truncated cone to obtain the required depth, the values shown for depths greater than 14 or 15 inches are not considered as reliable as those for less depths, as the sand could flow more freely because of the absence of lateral support. The curves show the maximum load sustained to increase but slowly from a depth of 18 inches to a depth of about 10 inches, and at a much faster rate as the depth decreases below 10 inches. The form of the curves seem to indicate that a certain depth might soon be reached beyond which the maximum load sustained would become constant. The relative positions of the curves show that in general the greater area supports the greater unit load. This is as might be expected because the smaller the area the more nearly a concentrated load is obtained, and the easier the plate can be thrust down without disturbing any considerable portion of the bed of sand.

Plates 5 to 24 show in various ways the plotted data for deter-

mining the variation of intensity of pressure with the depth and with distance from the center of applied pressure. Plates 5 to 14 show the relation between the average unit pressure applied and the average unit pressure transmitted for depths of sand of 6, 12, and 18 inches, and distances from the center of pressure of 5, 6, and 12 inches. Because these curves are plotted to different scales they are not so well adapted to making comparisons as plates 15 to 21. In plates 15 to 18 all curves on one plate show by their position how the pressure transmitted increases or decreases with the depth for a constant distance from the center of pressure. It is interesting to note that for distances of jack from plug of 0, 5, and 6 inches, the pressure transmitted decreases with increasing depth, while for jack 12 inches from plug, the pressure transmitted increases with increasing depth. This is easily explained by the fact that for distances of center of plate from center of plug not exceeding 6 inches, the plate extended far enough to rest directly over either all or part of the plug, and the pressure transmitted increased with decreasing depth in a manner similar to the case for jack 0 inches from plug. With a distance of 12 inches center of plate to center of plug, no part of the plate lay directly over any portion of the plug, and the pressure could not be transferred vertically downward.

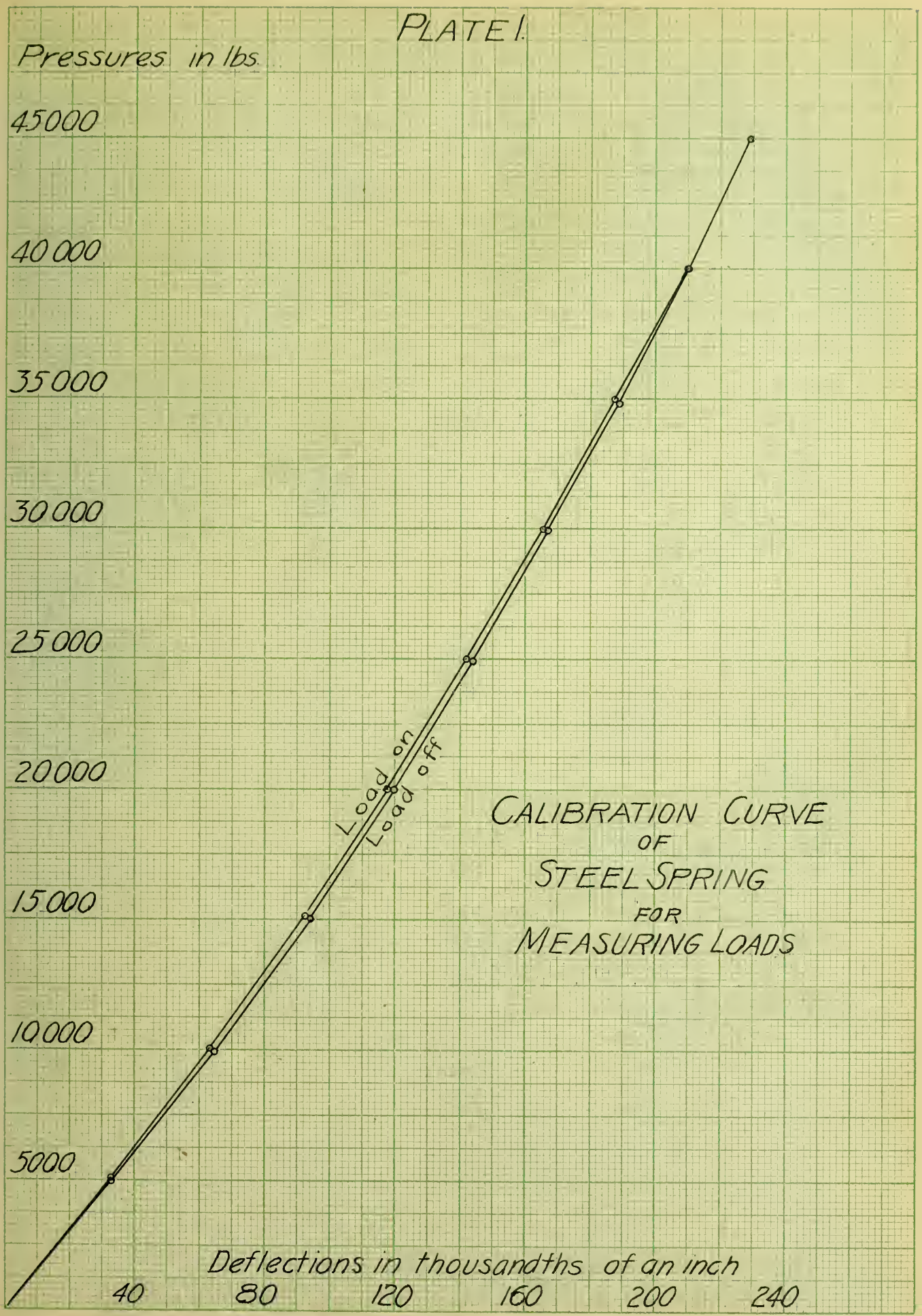
Plates 19 to 21 show how the pressure transmitted varies with the distance from the center of applied pressure when the depth is constant. In all cases the pressure transmitted decreases as the distance from the center of applied pressure increases. This is in direct opposition to part of Mr. Burnell's thesis on the same subject. Mr. Burnell found that for dry sand 18 inches deep , a greater pressure was transmitted with jack 6 inches from plug than for jack 0 inches from plug

which indicated strong arch action. As the floor of Mr. Burnell's apparatus was made of planks which would bend easily, his results were very likely to be affected by this bending, and his conclusion in regard to arch action taking place is thought to be erroneous.

Plates 15 to 21 show that for jack directly over the plug and with sand 6 inches deep, the average unit pressure transmitted is considerably greater than the average unit pressure applied. They also show the pressure to be transmitted to an area of the supporting surface larger than the area loaded, or that the pressure "spreads out". The explanation for a greater average unit pressure transmitted than applied is therefore found by supposing the plate did not bear uniformly upon the sand bed. Undoubtedly, the intensity of pressure under the loaded plate decreased from a maximum for points directly beneath its center to much smaller values near the outer edge. It is thus seen that for small depths, when the plug was directly under the center of the plate, it rereived a greater pressure than the average obtained by dividing the total load on the plate by the area of the plate.

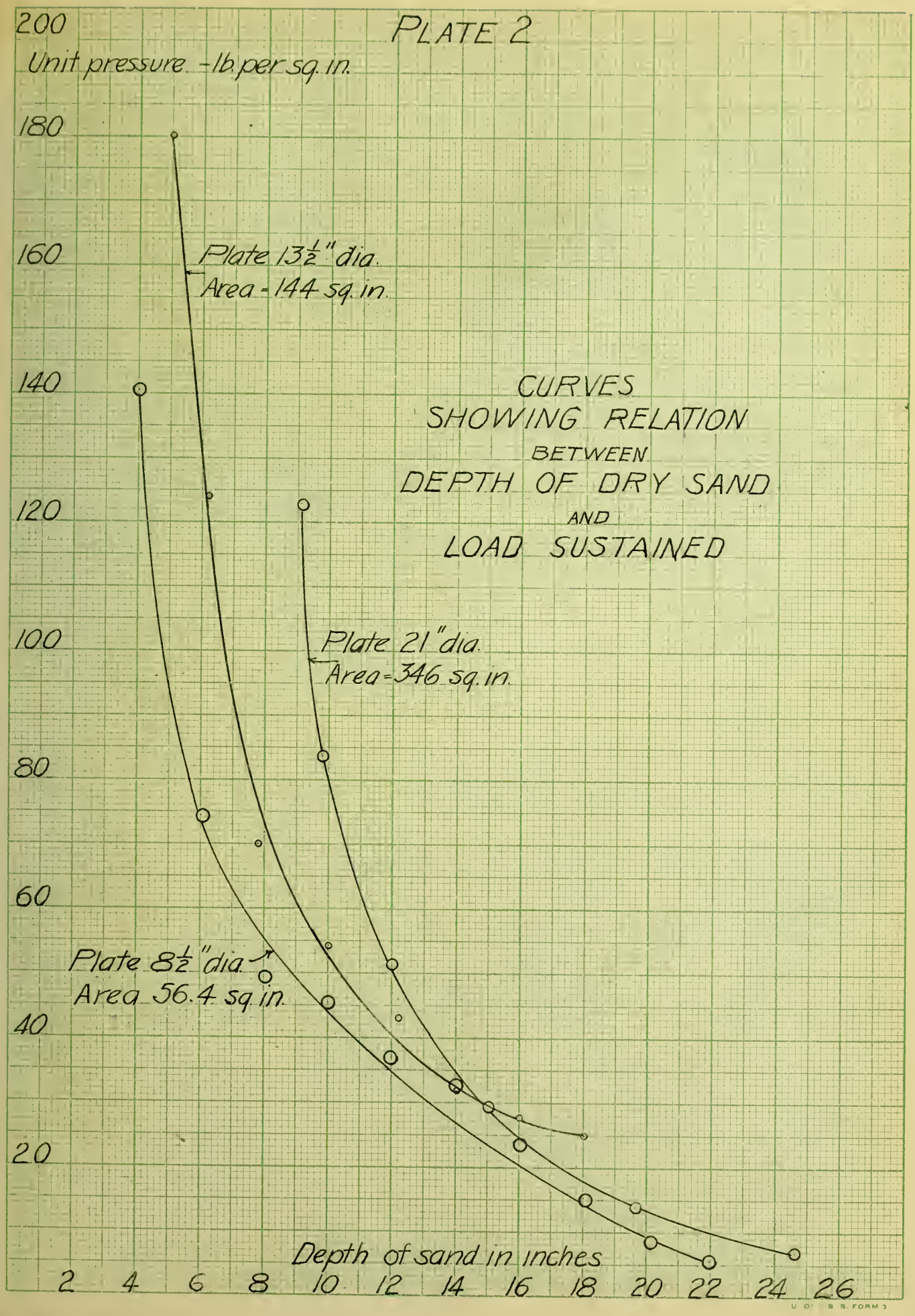
The shape of the lines of equal pressure through the sand cannot be determined with any certainty from the data. However, if it may be assumed that the distribution of pressure on a plane a certain distance below a loaded surface is approximately the same whether the sand at the plane rests upon a solid surface or is supported by more sand below, then the distribution would be as shown by plate 26. The average unit pressures transmitted are plotted with a total load of 3000 pounds on the plate, for varying depths and varying distances from the center of the plate. The interpolated lines show lines of equal pressure. The sketch is included in this thesis more as an interesting possibility

PLATE I.



U. OF I. S. FORM 3

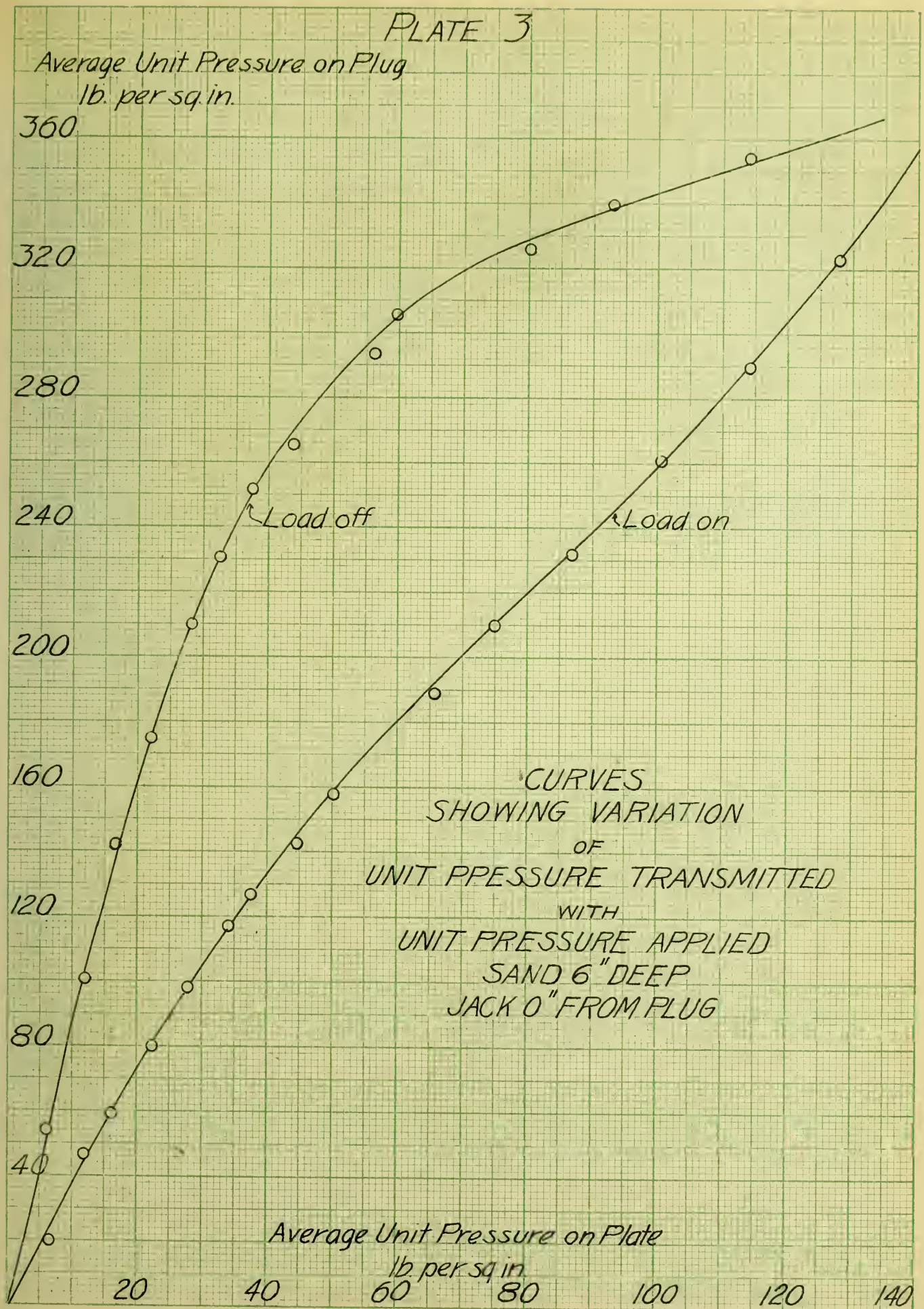
PLATE 2



CURVES
SHOWING RELATION
BETWEEN
DEPTH OF DRY SAND
AND
LOAD SUSTAINED

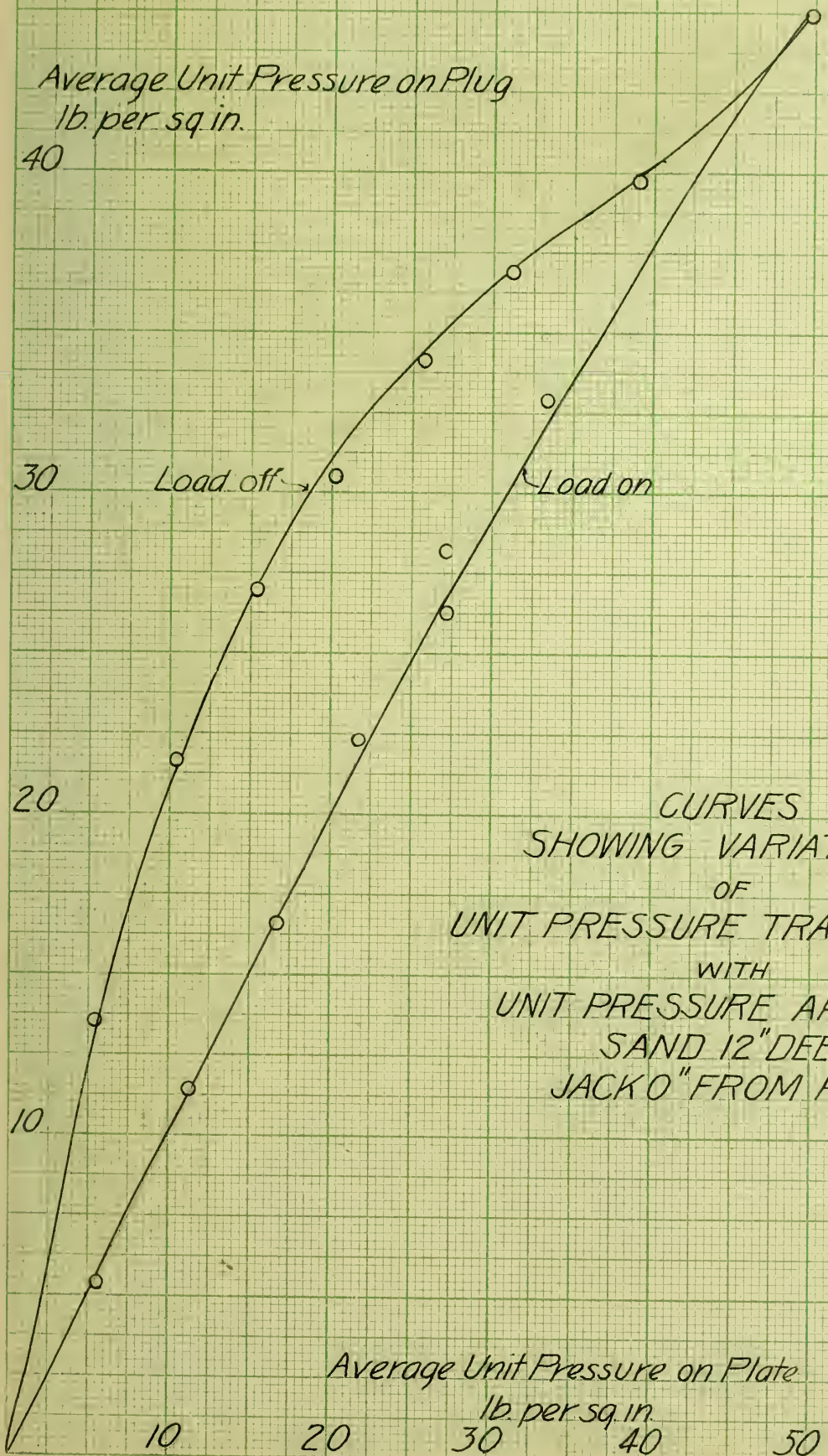
U. O. S. S. FORM 3

PLATE 3



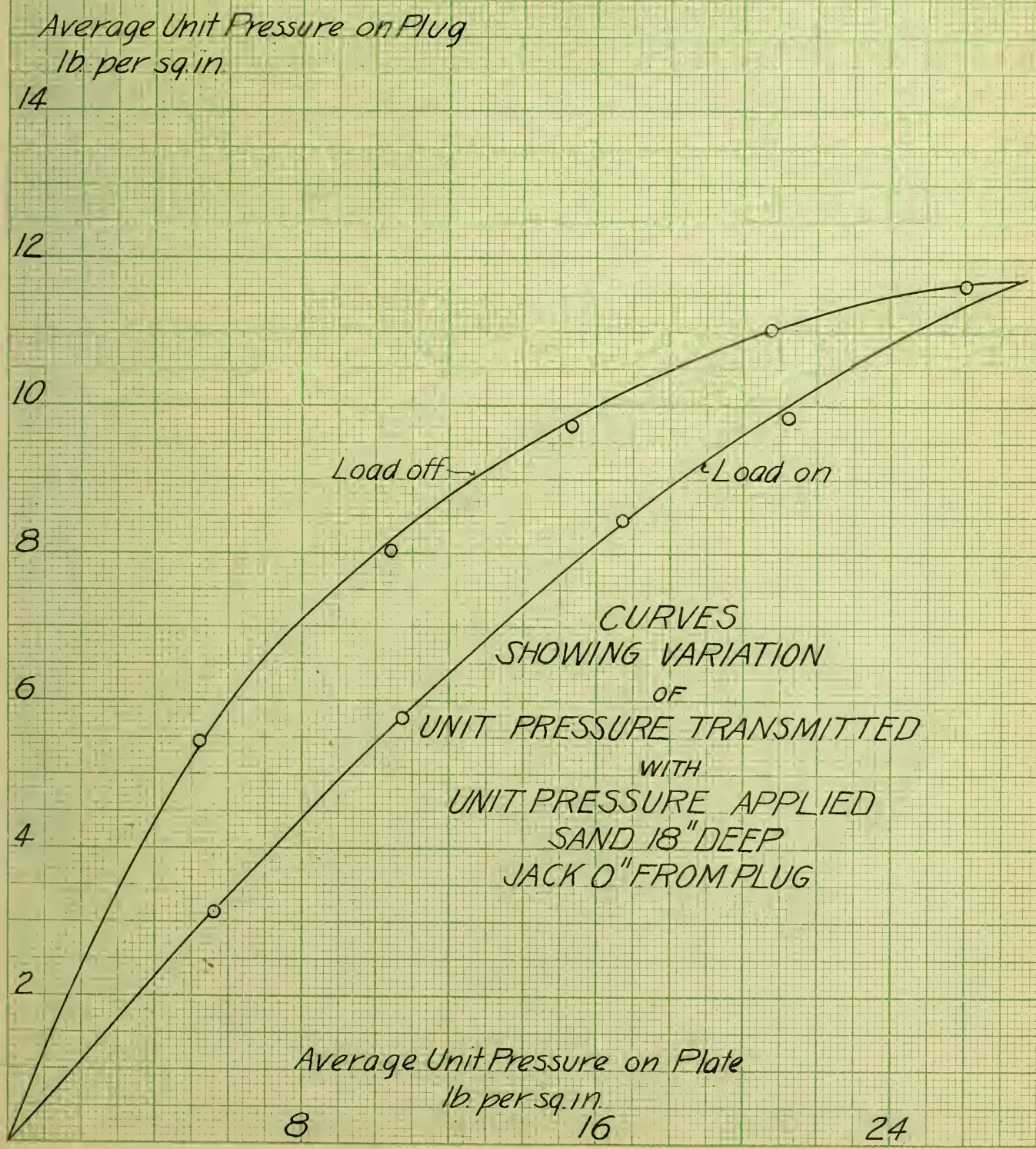
U. OF I. S. 6. FORM 3

PLATE 4



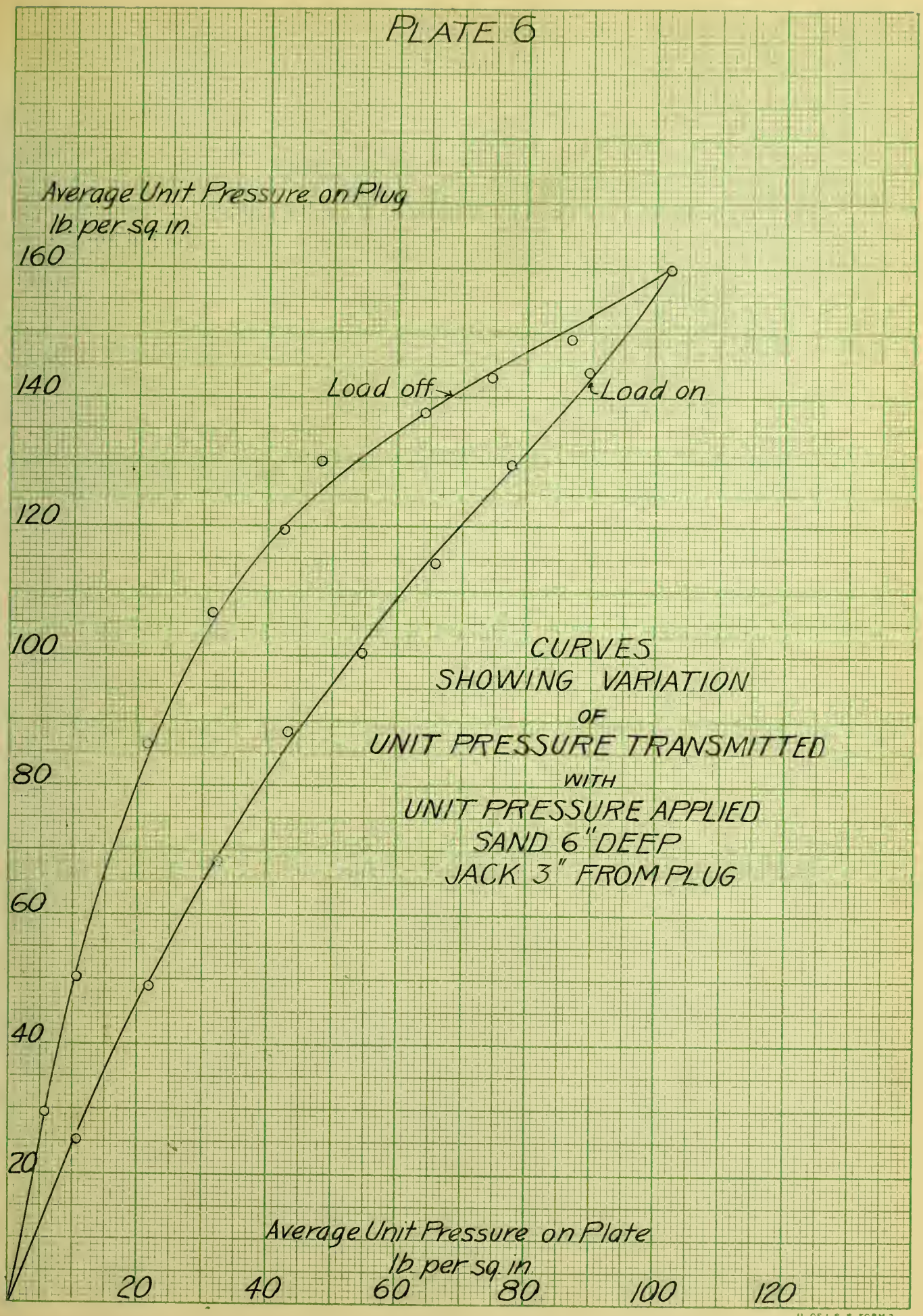
U. OF I. S. S. FORM 3

PLATE 5



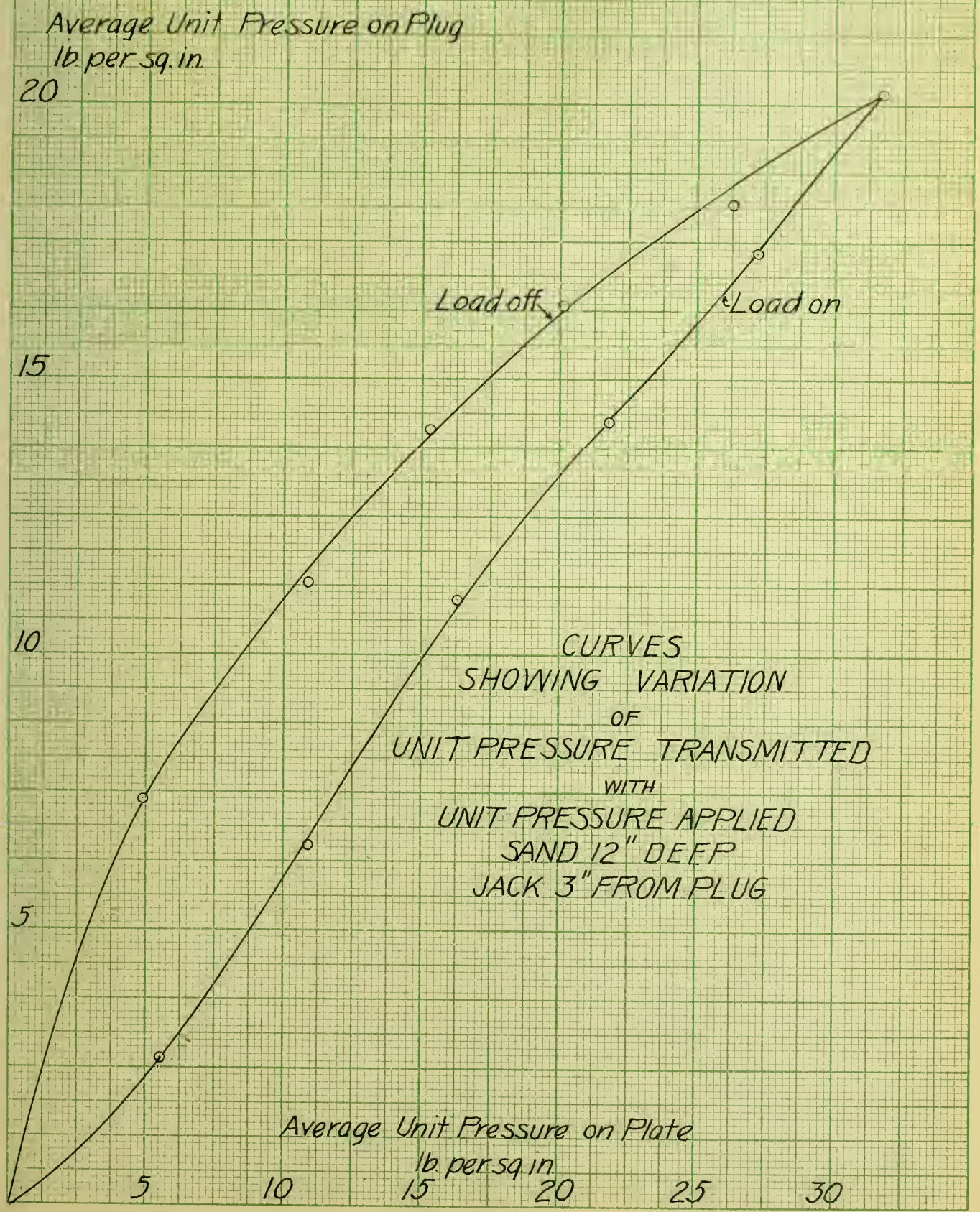
U. OF I. S. S. FORM 3

PLATE 6



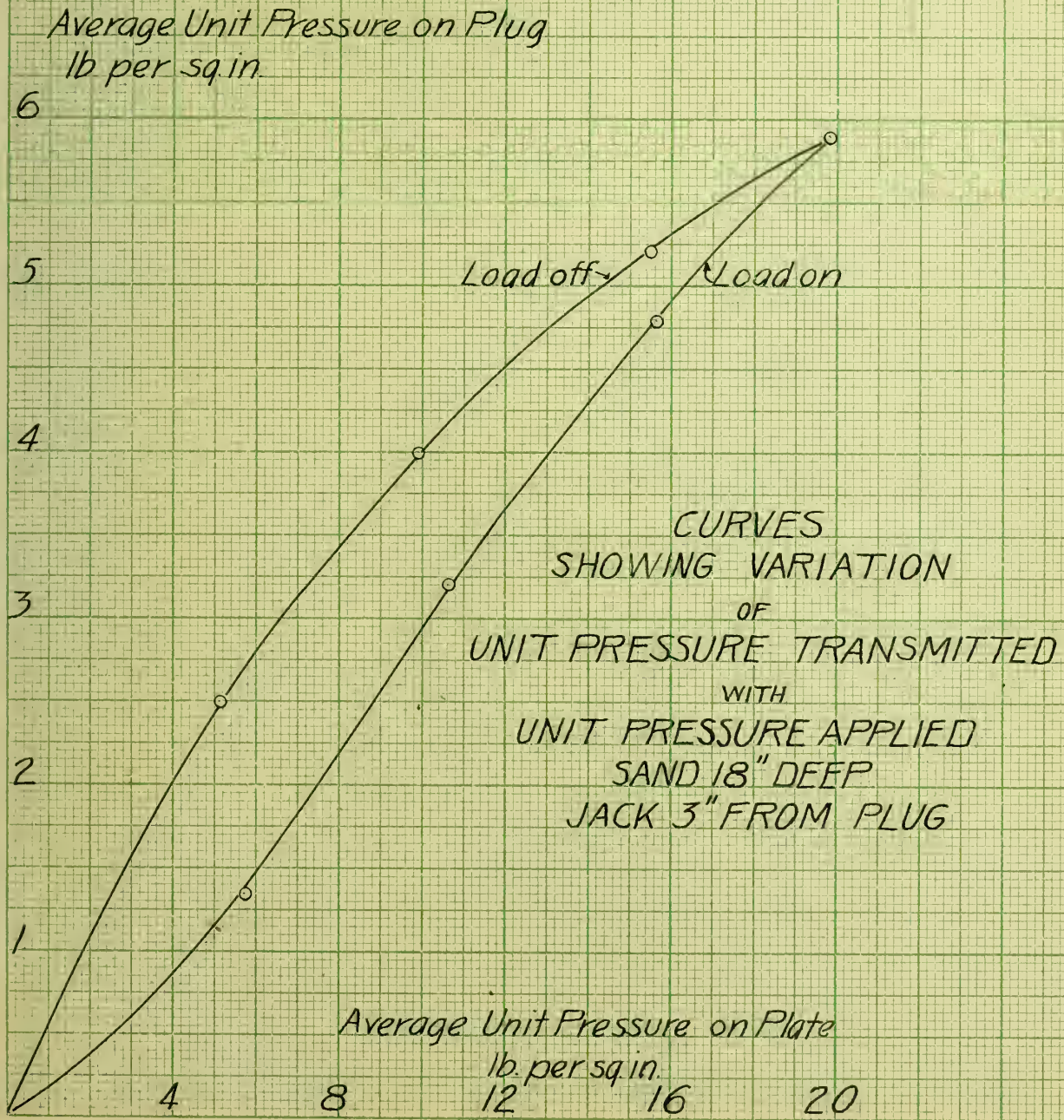
U. OF I. S. S. FORM 3

PLATE 7



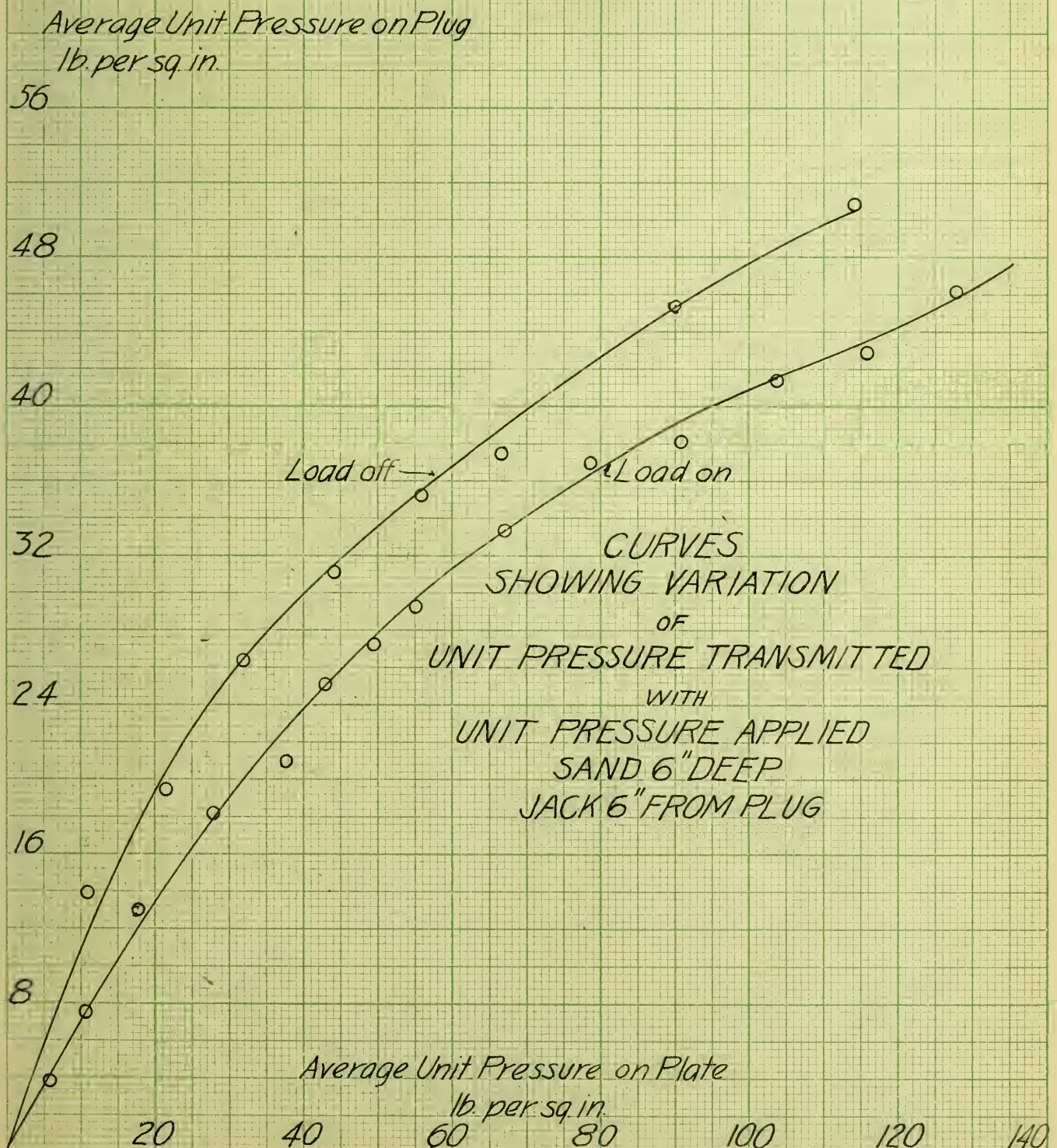
U. OF I. S. S. FORM 3

PLATE 8



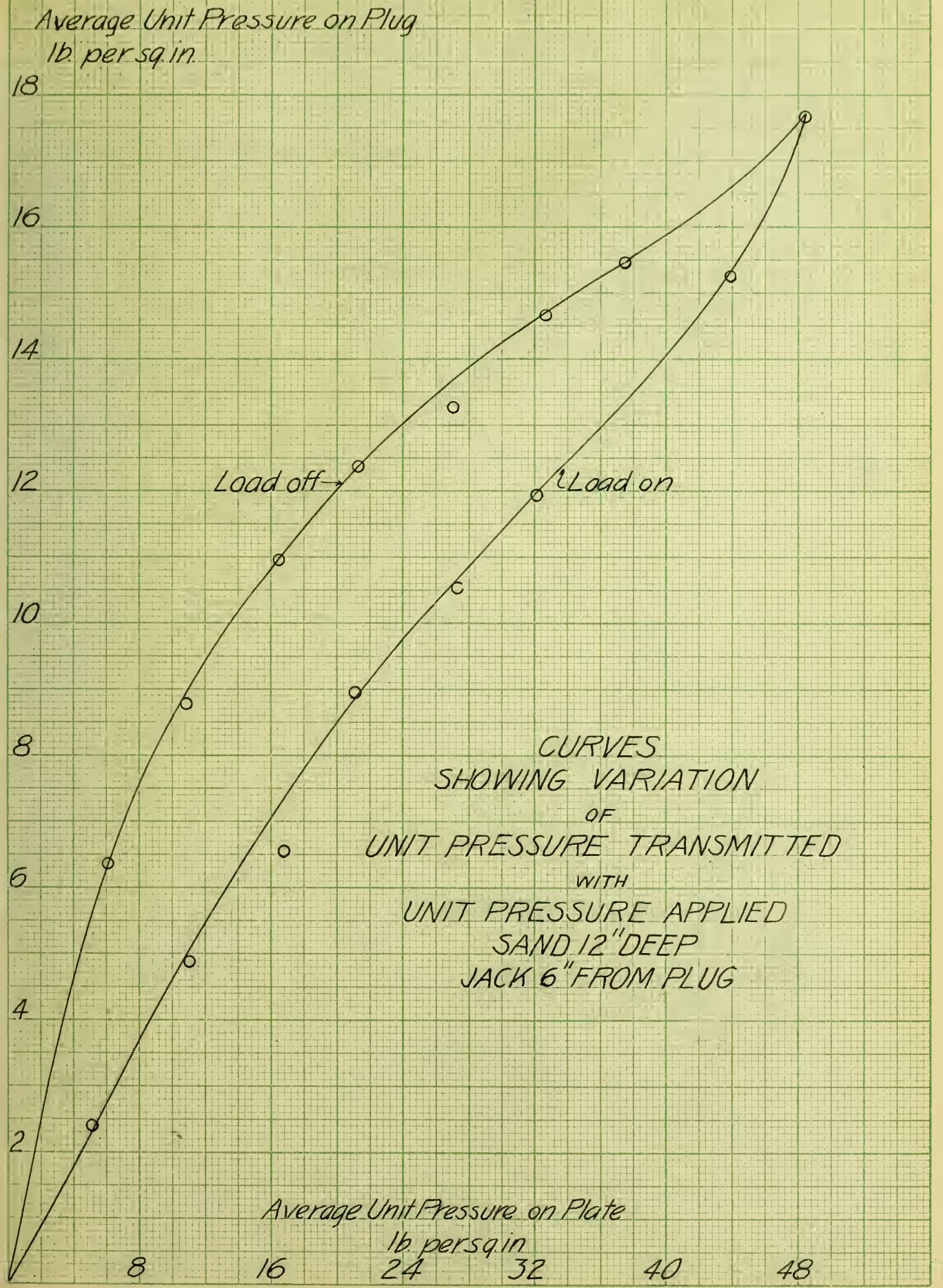
U. OF I. S. FORM 3

PLATE 9



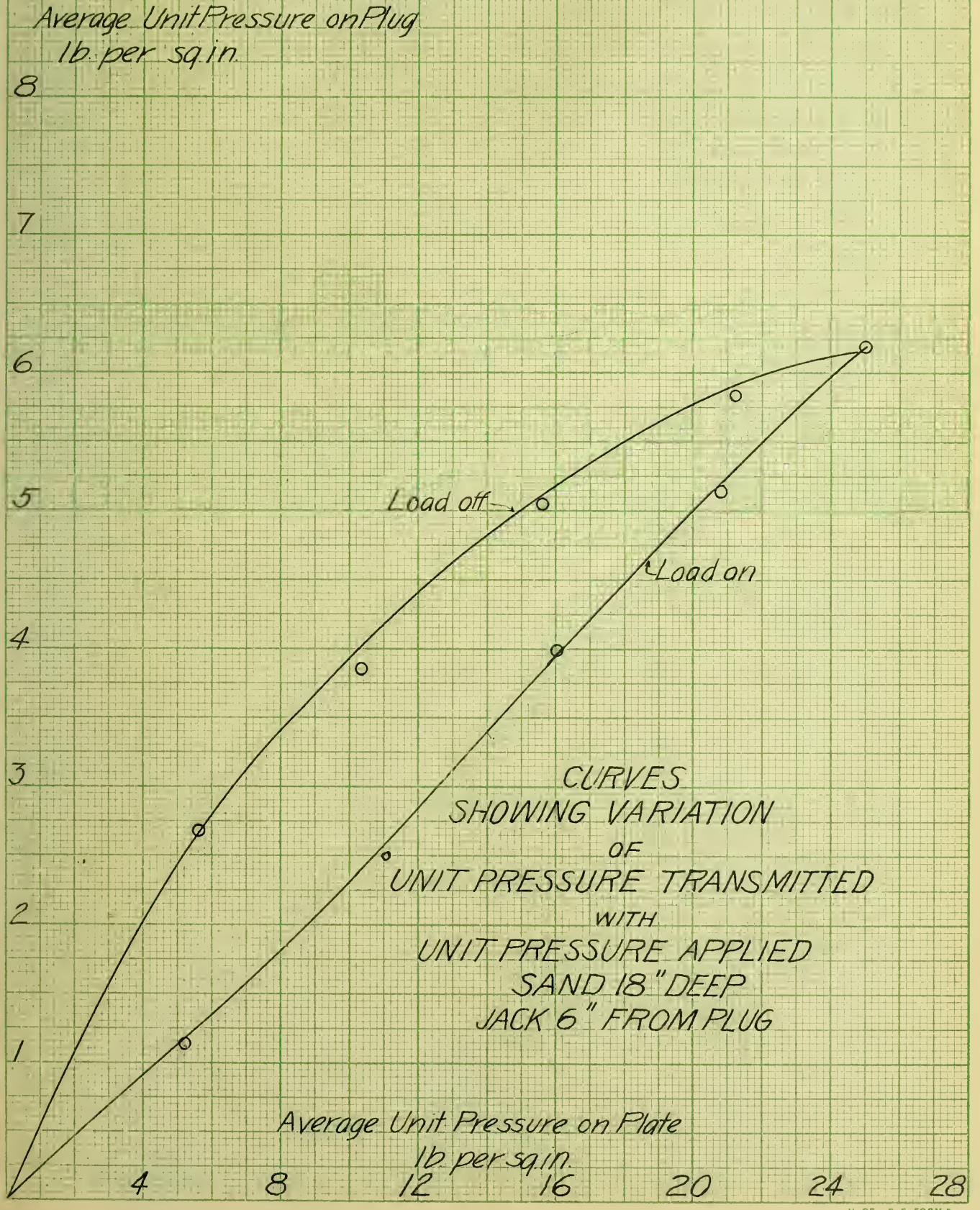
U. OF I. S. S. FORM 3

PLATE 10



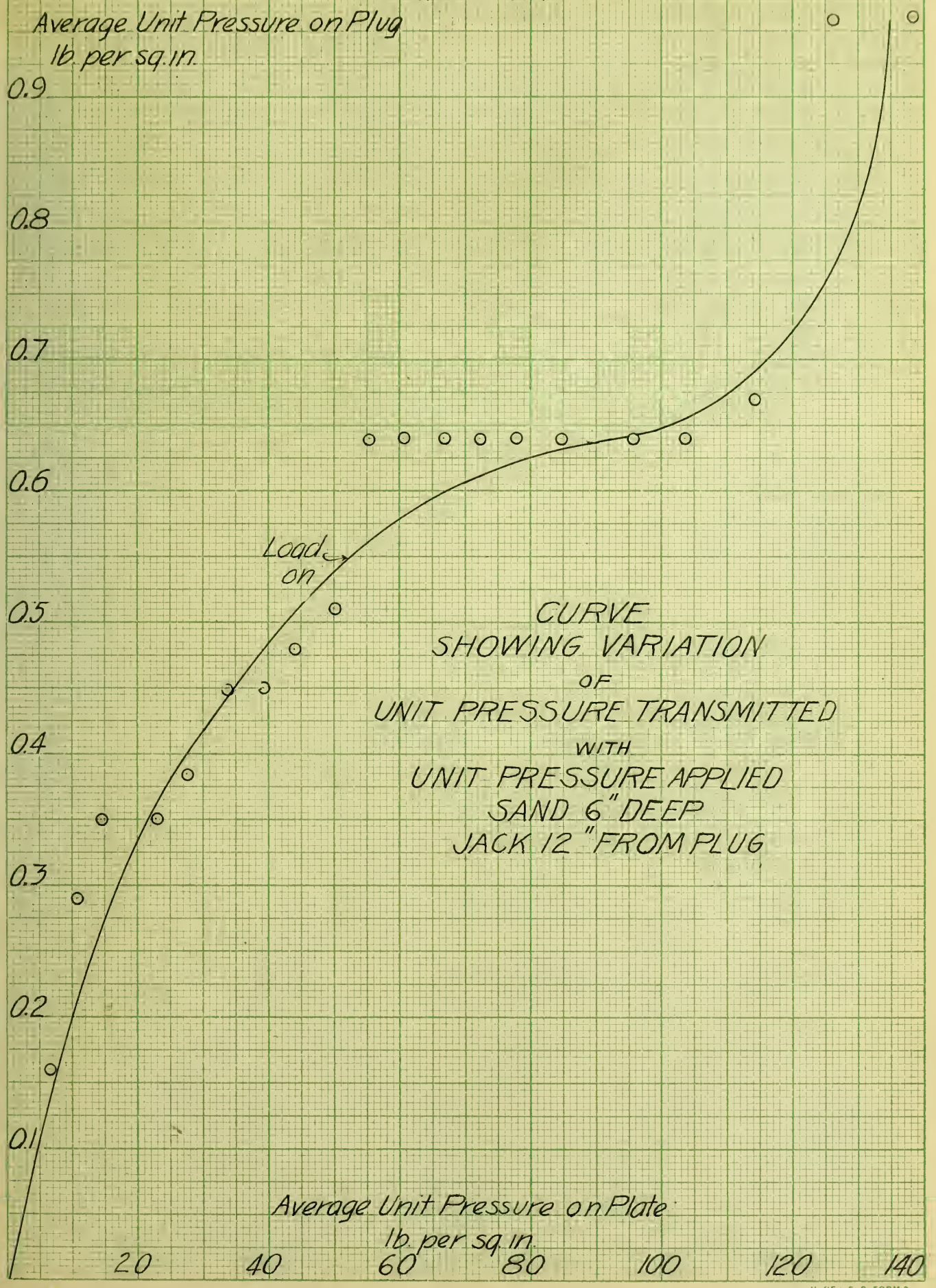
U. OF I. S. S. FORM 3

PLATE II



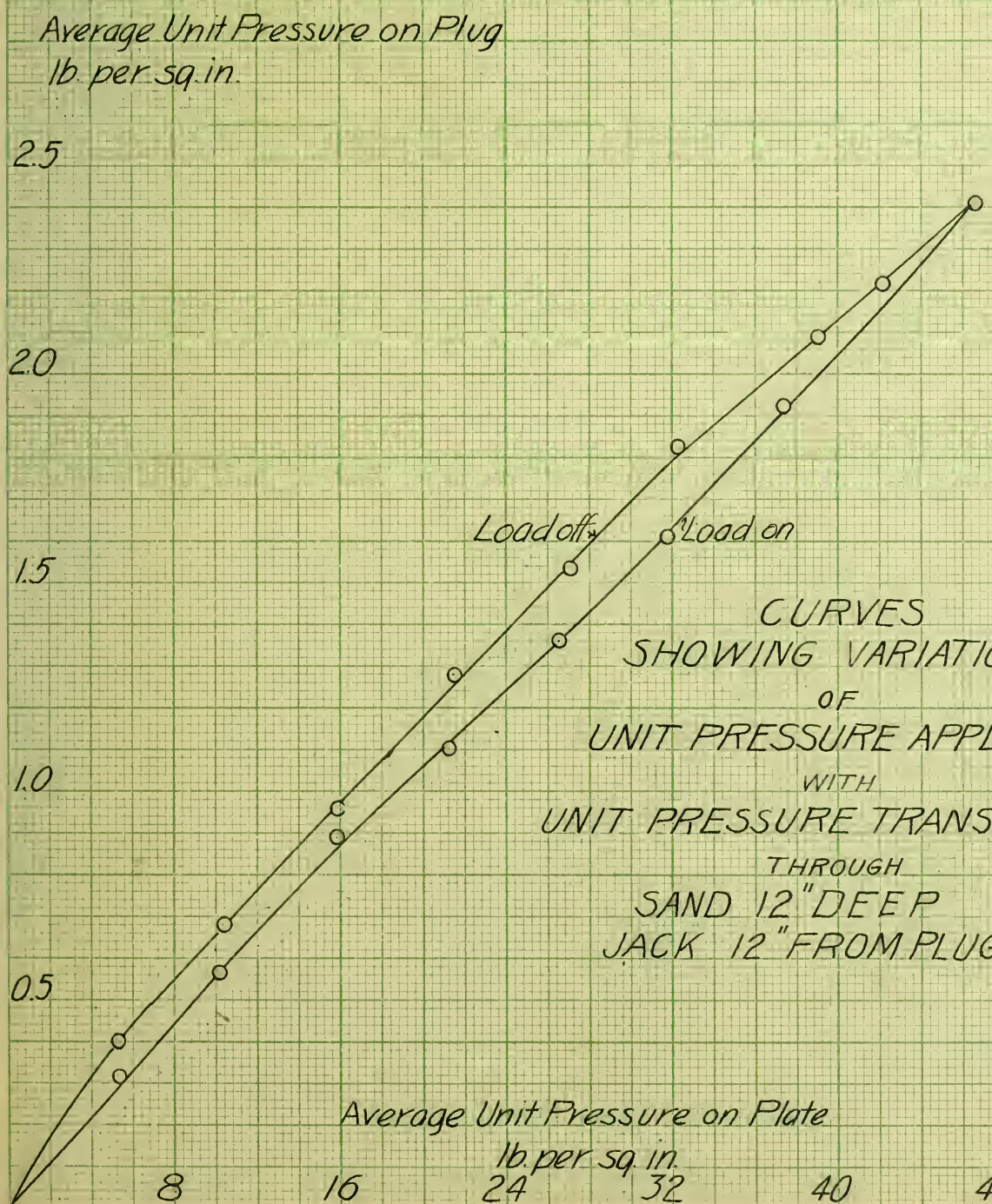
U. OF I. S. S. FORM 3

PLATE 12



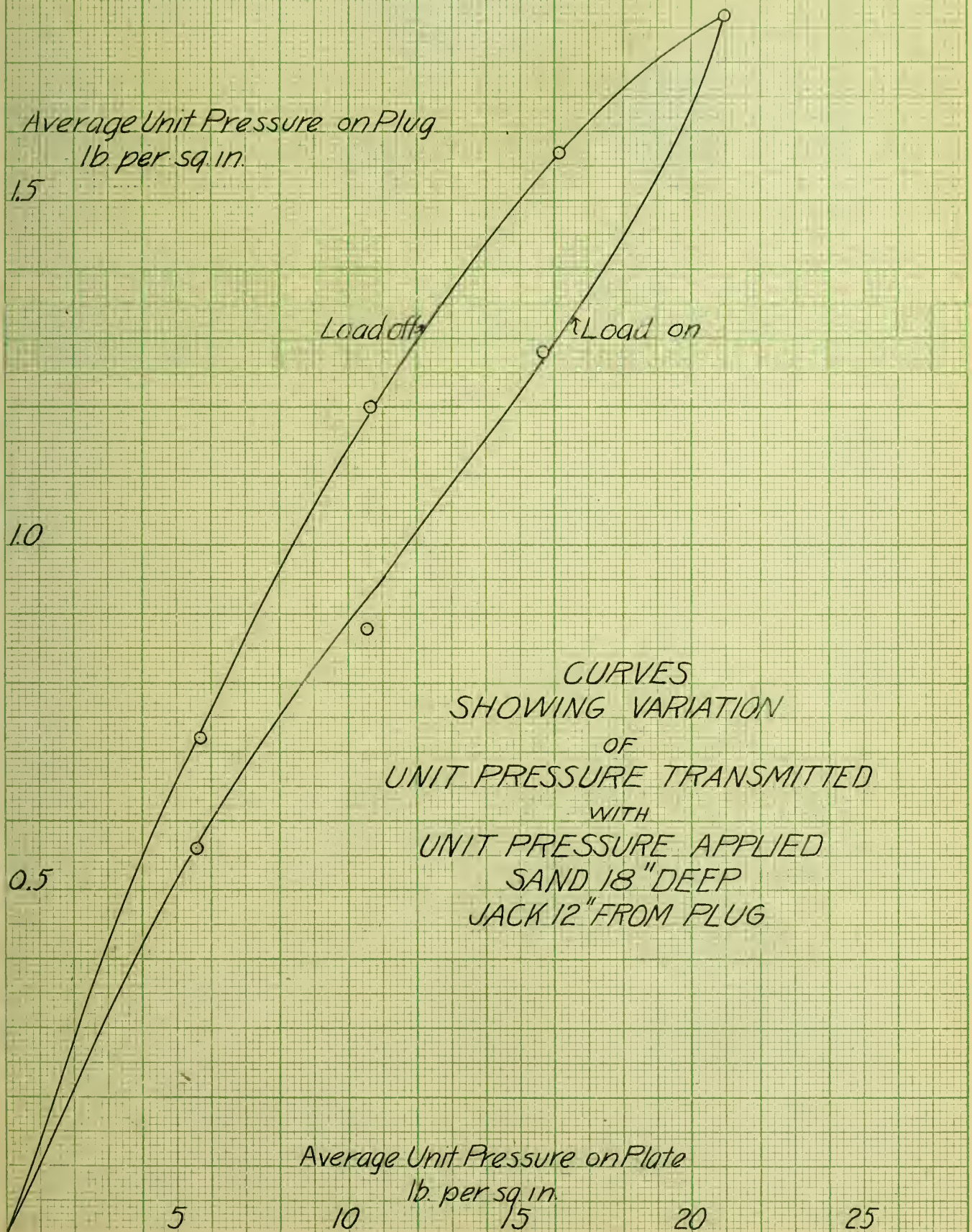
U. OF I. S. S. FORM 3

PLATE 13



U. OF I. S. S. FORM 3

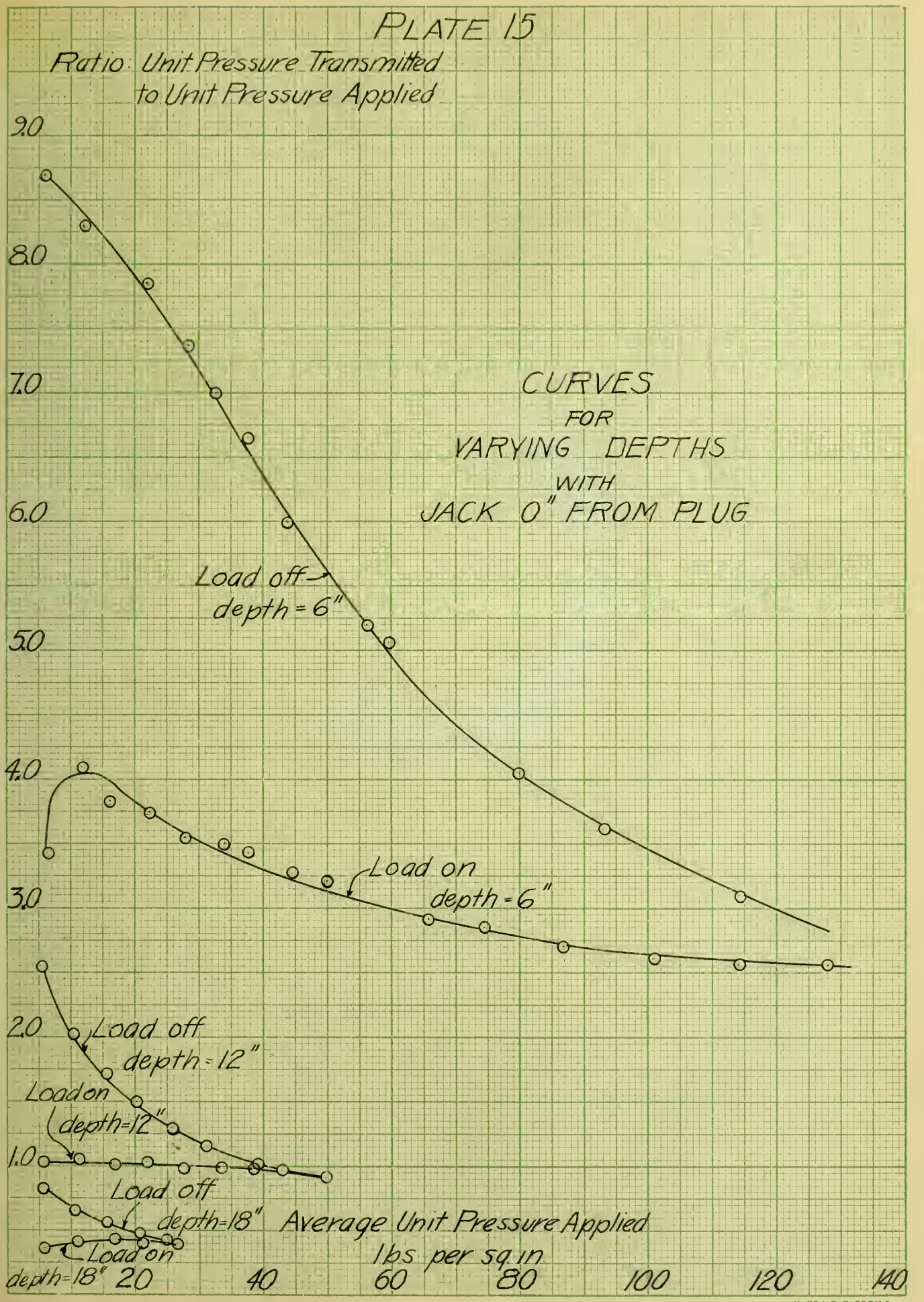
PLATE 14



CURVES
SHOWING VARIATION
OF
UNIT PRESSURE TRANSMITTED
WITH
UNIT PRESSURE APPLIED
SAND 18" DEEP
JACK 12" FROM PLUG

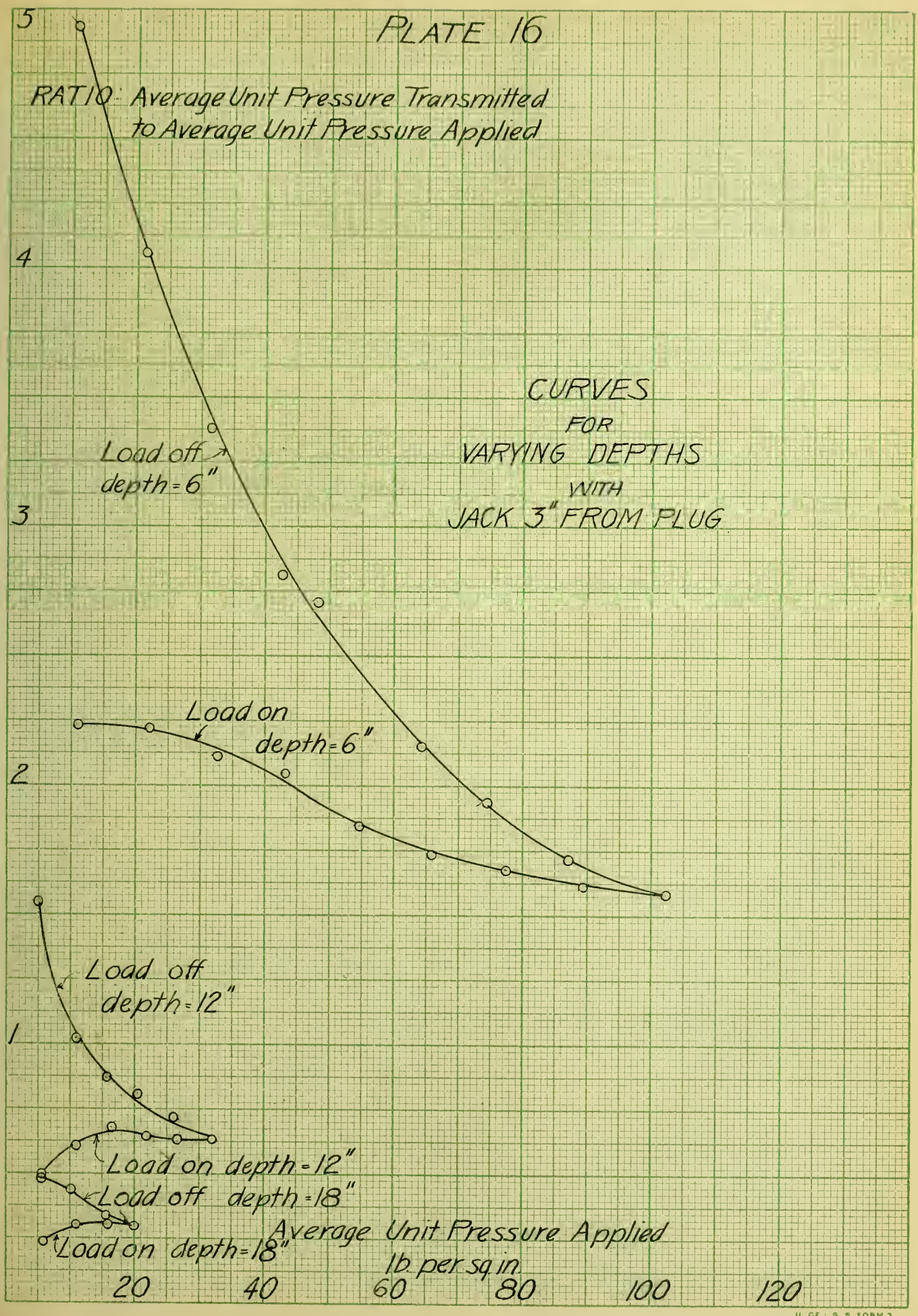
U. OF I. S. FORM 3

PLATE 15



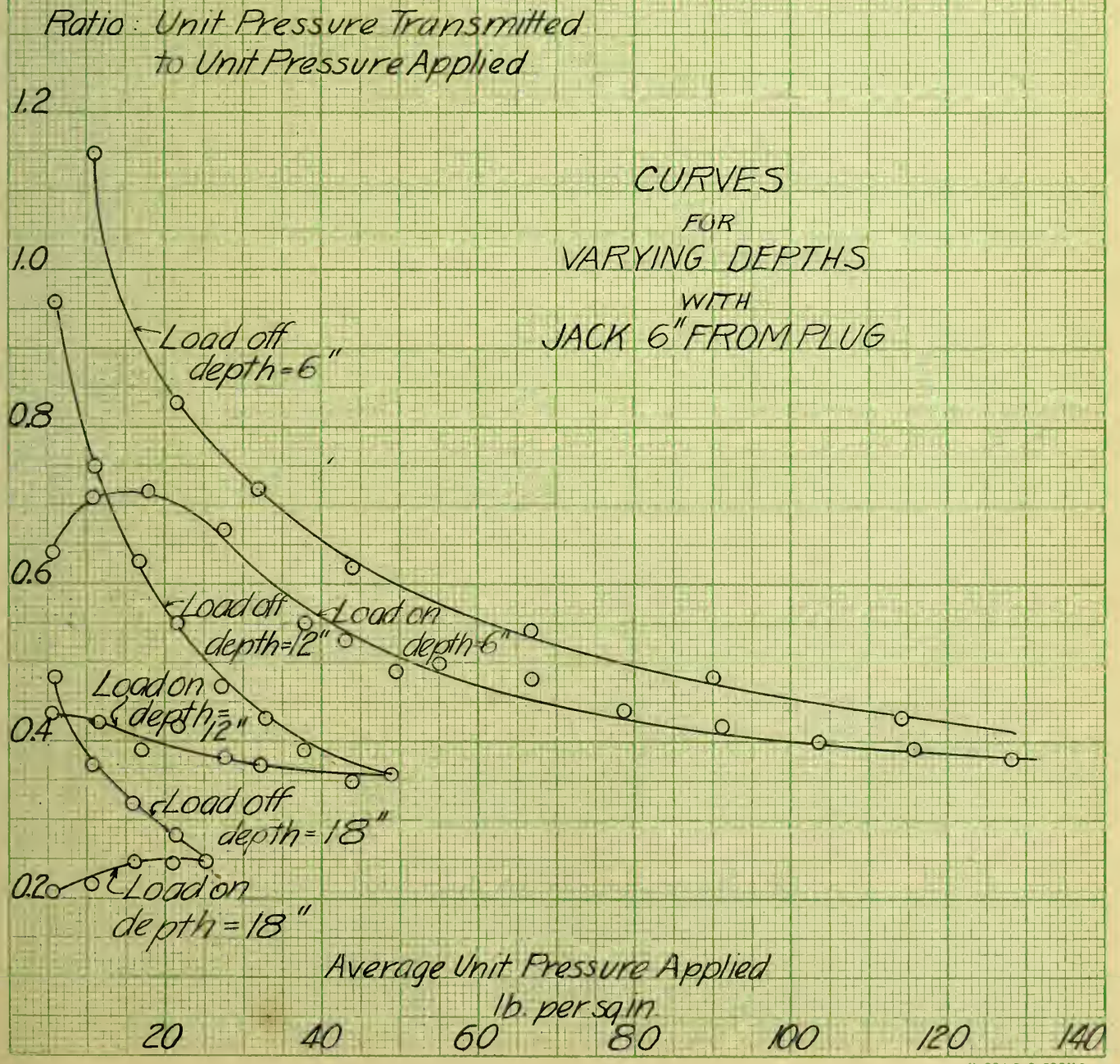
U. OF I. S. S. FORM 3

PLATE 16



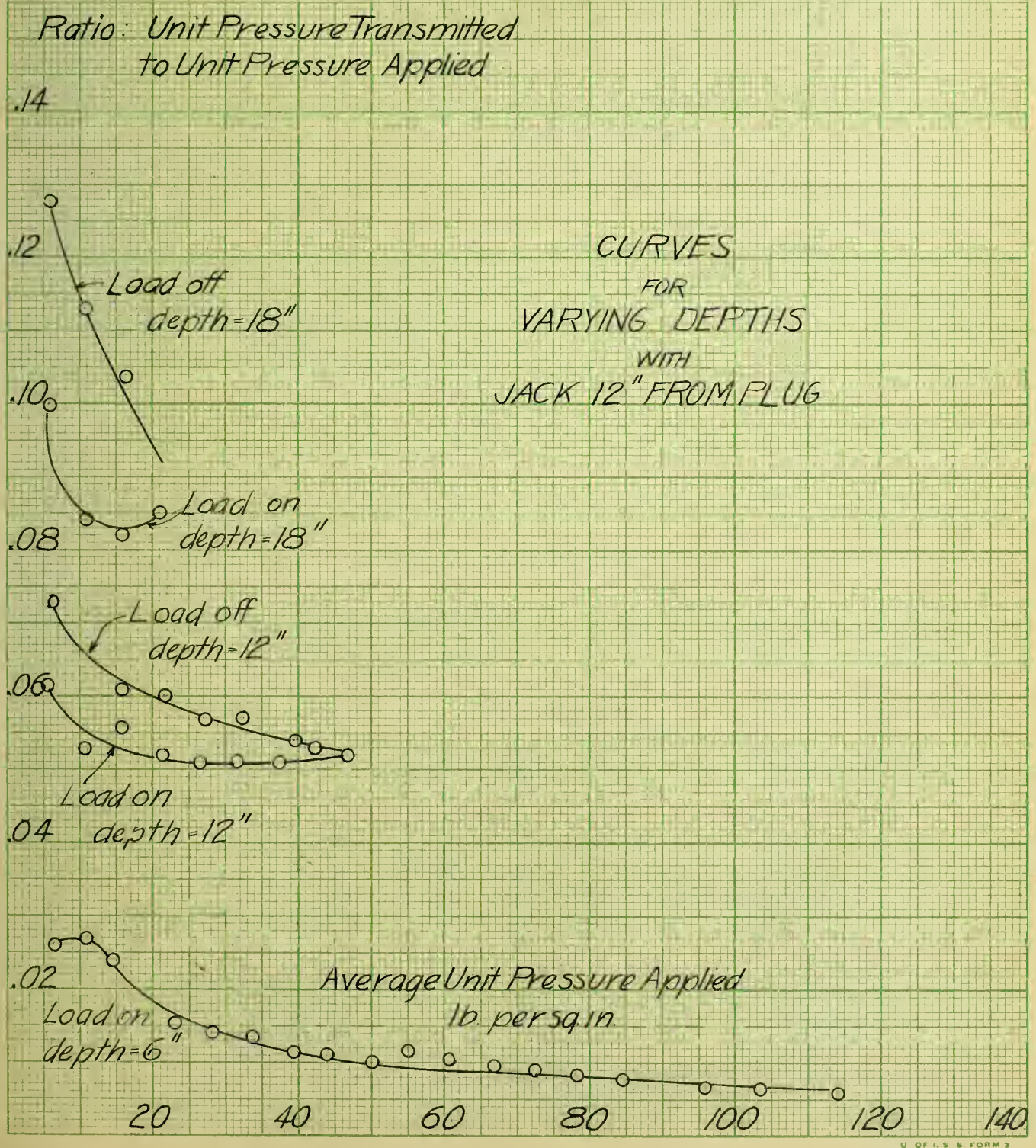
U. CF I. S. S. FORM 3

PLATE 17



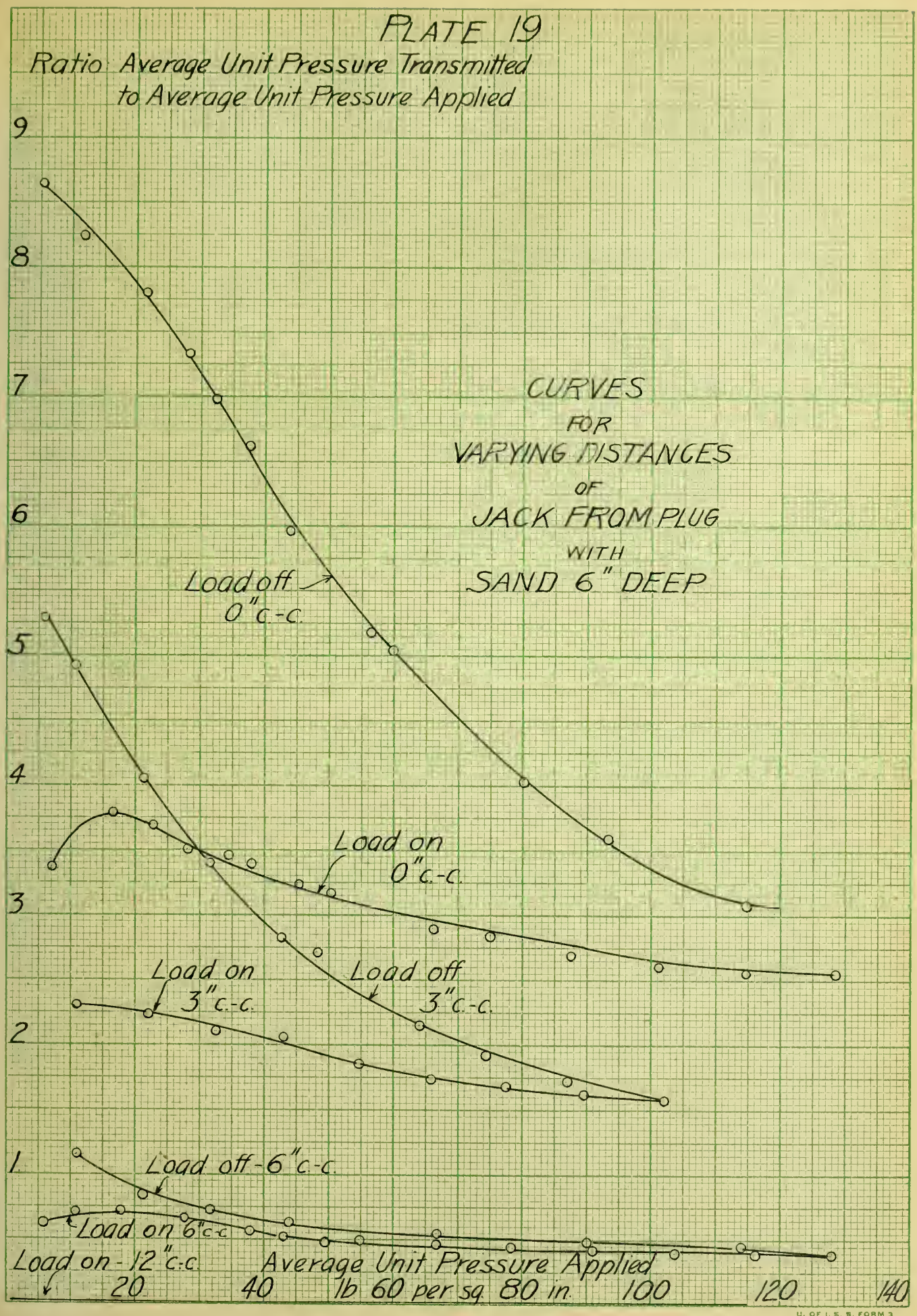
U. OF I. S. FORM 3

PLATE 18



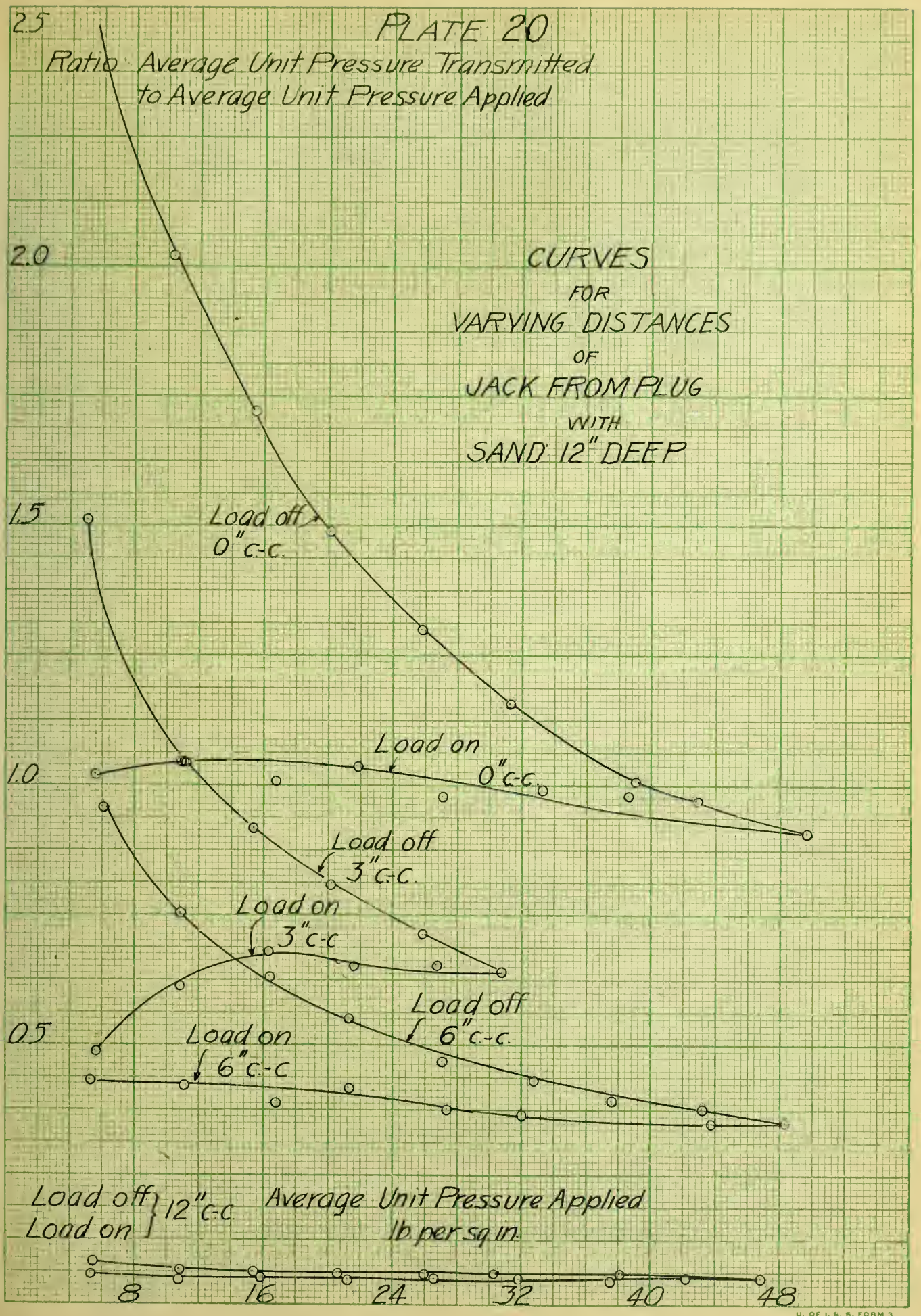
U. OF I. S. FORM 3

PLATE 19



U. OF I. S. FORM 3

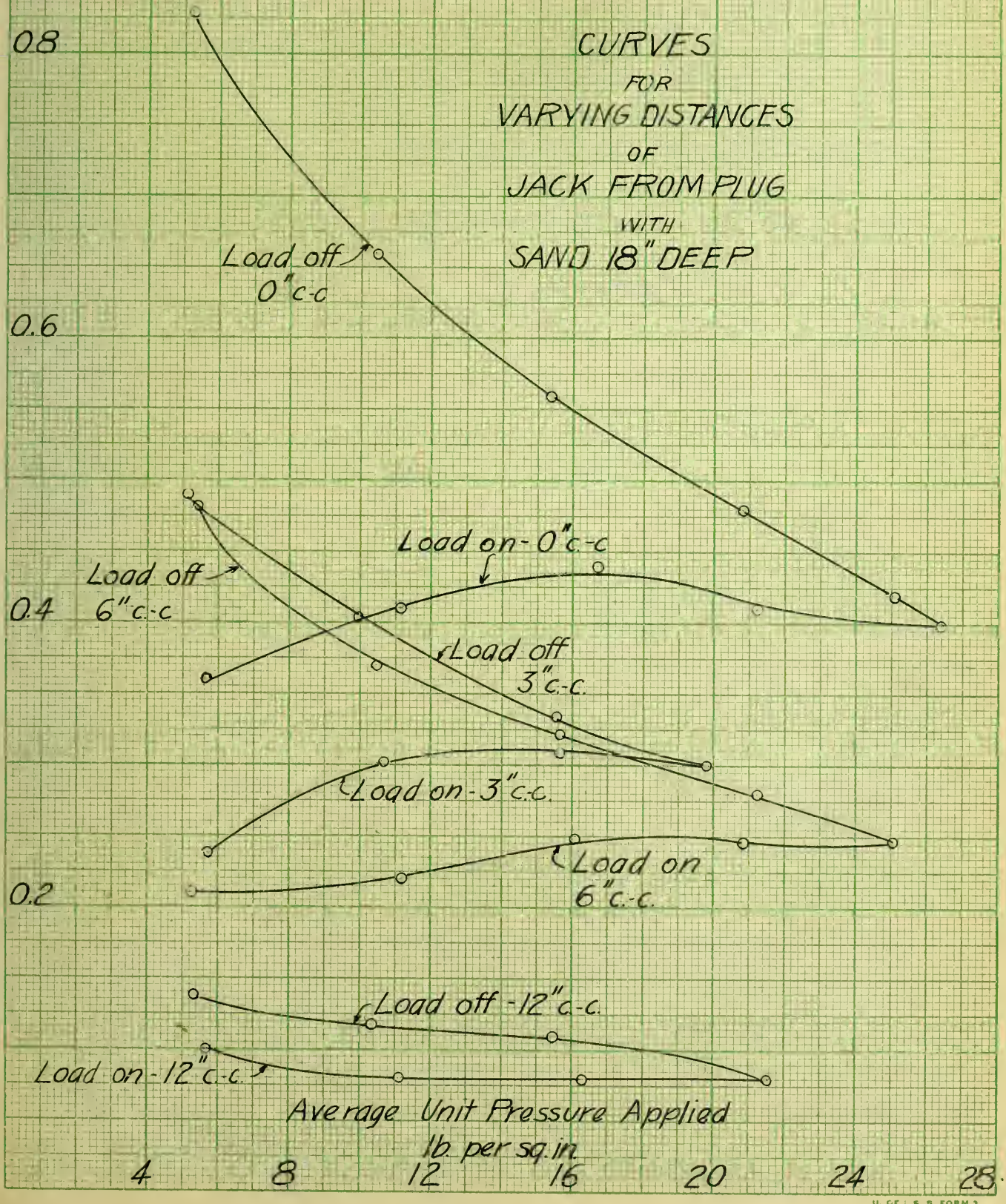
PLATE 20



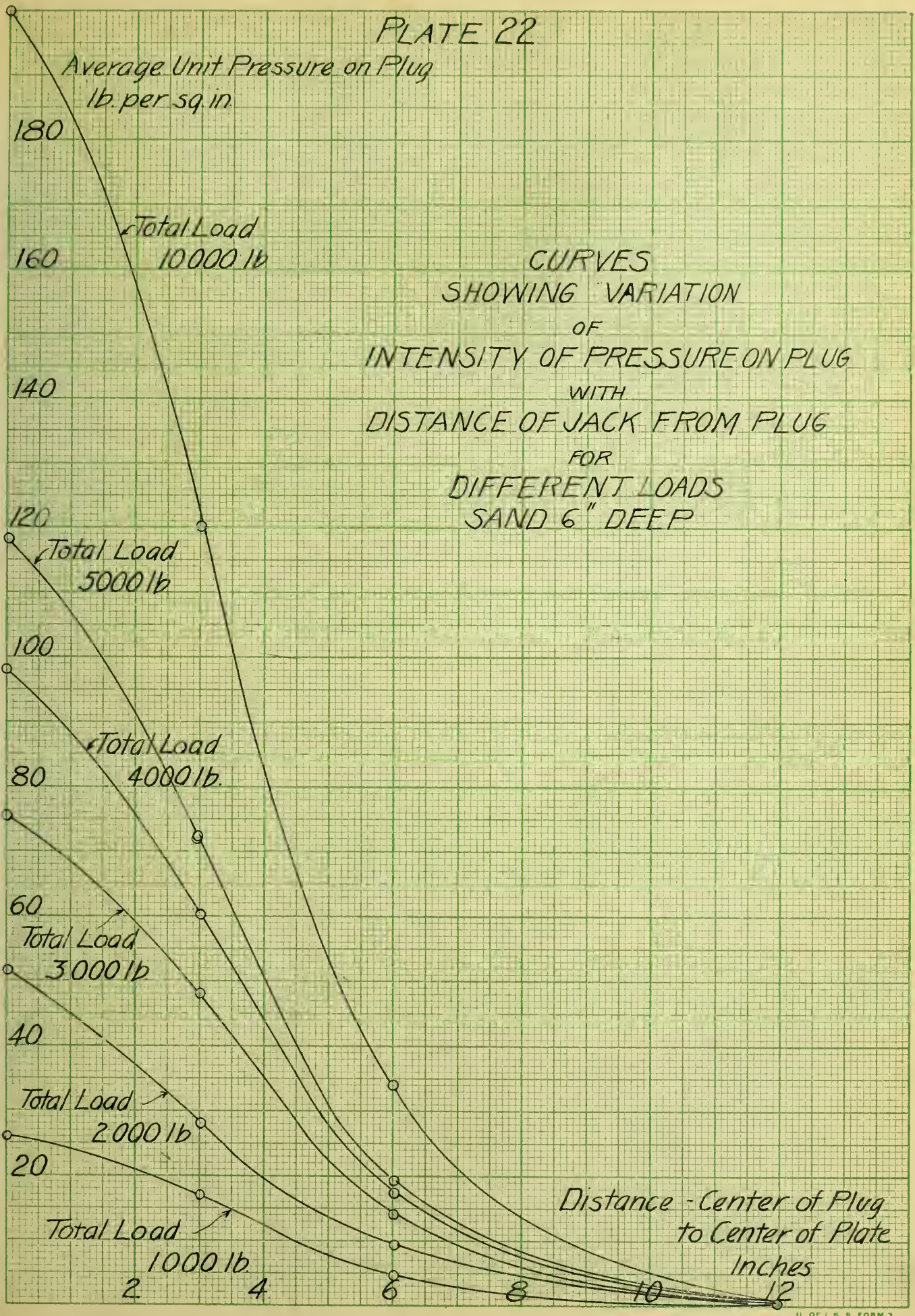
U. OF I. S. S. FORM 3

PLATE 21

Ratio: Average Unit Pressure Transmitted to Average Unit Pressure Applied

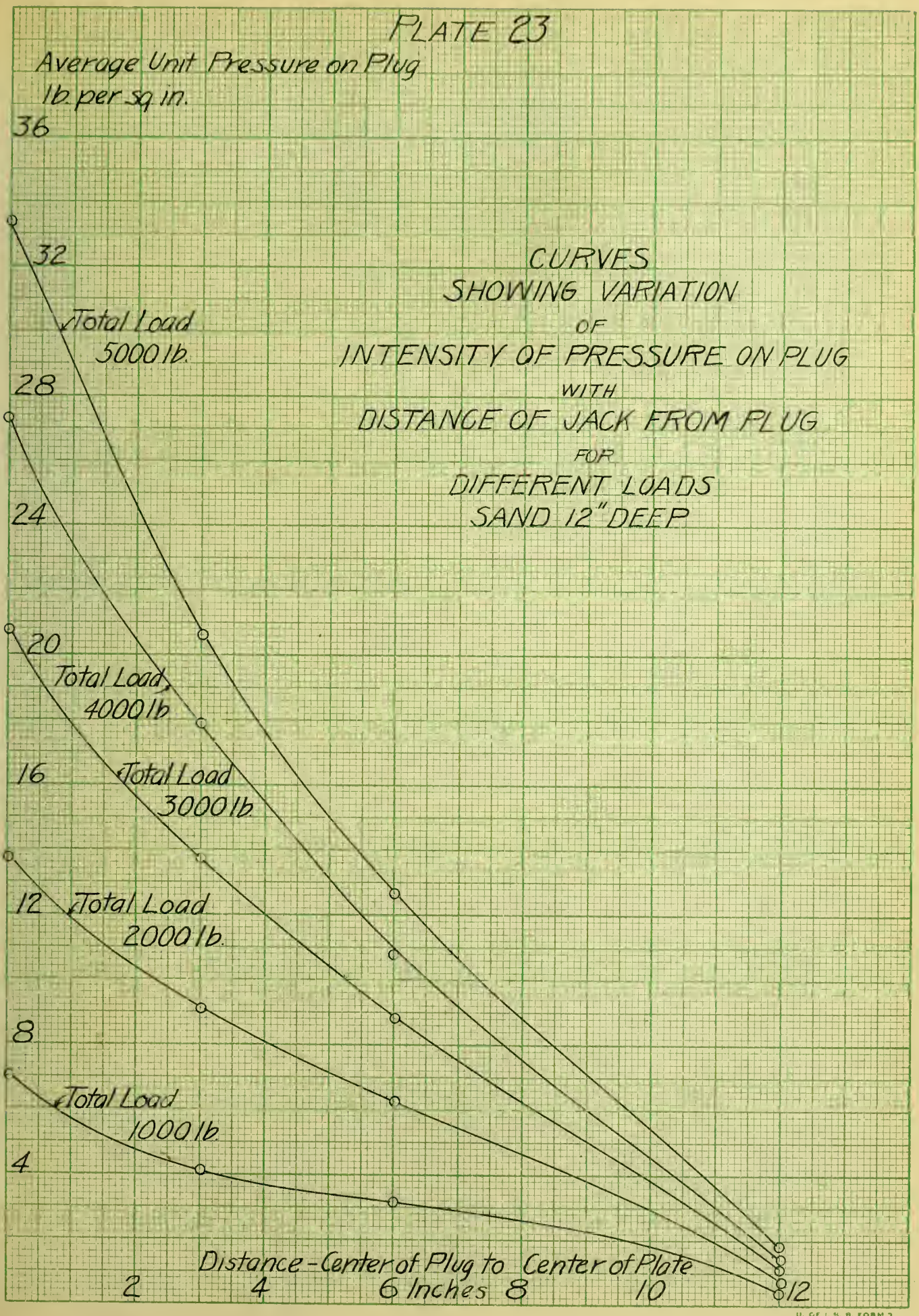


U. OF I. E. S. FORM 3



U. OF I. S. S. FORM 3

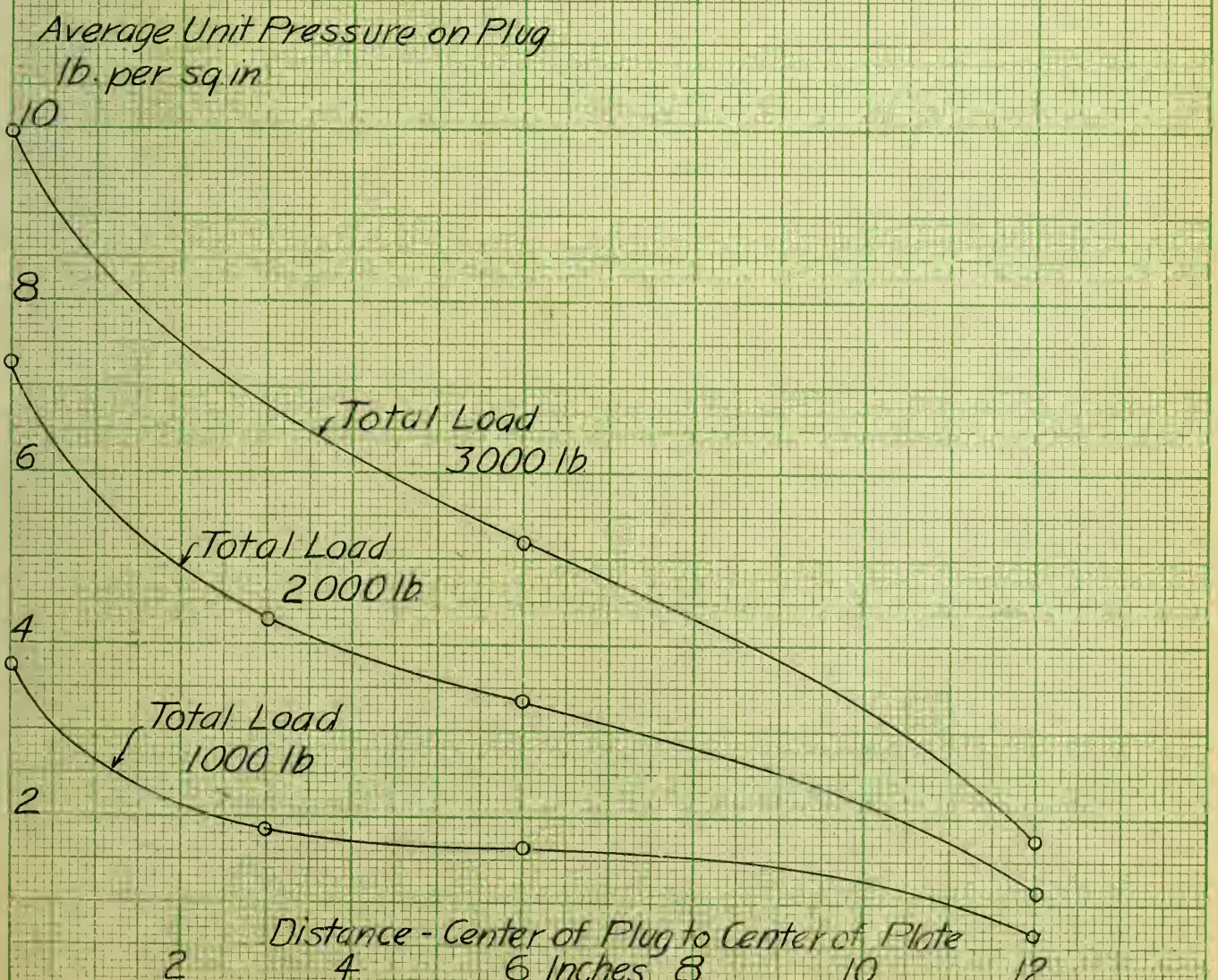
PLATE 23



U. OF I. S. B. FORM 3

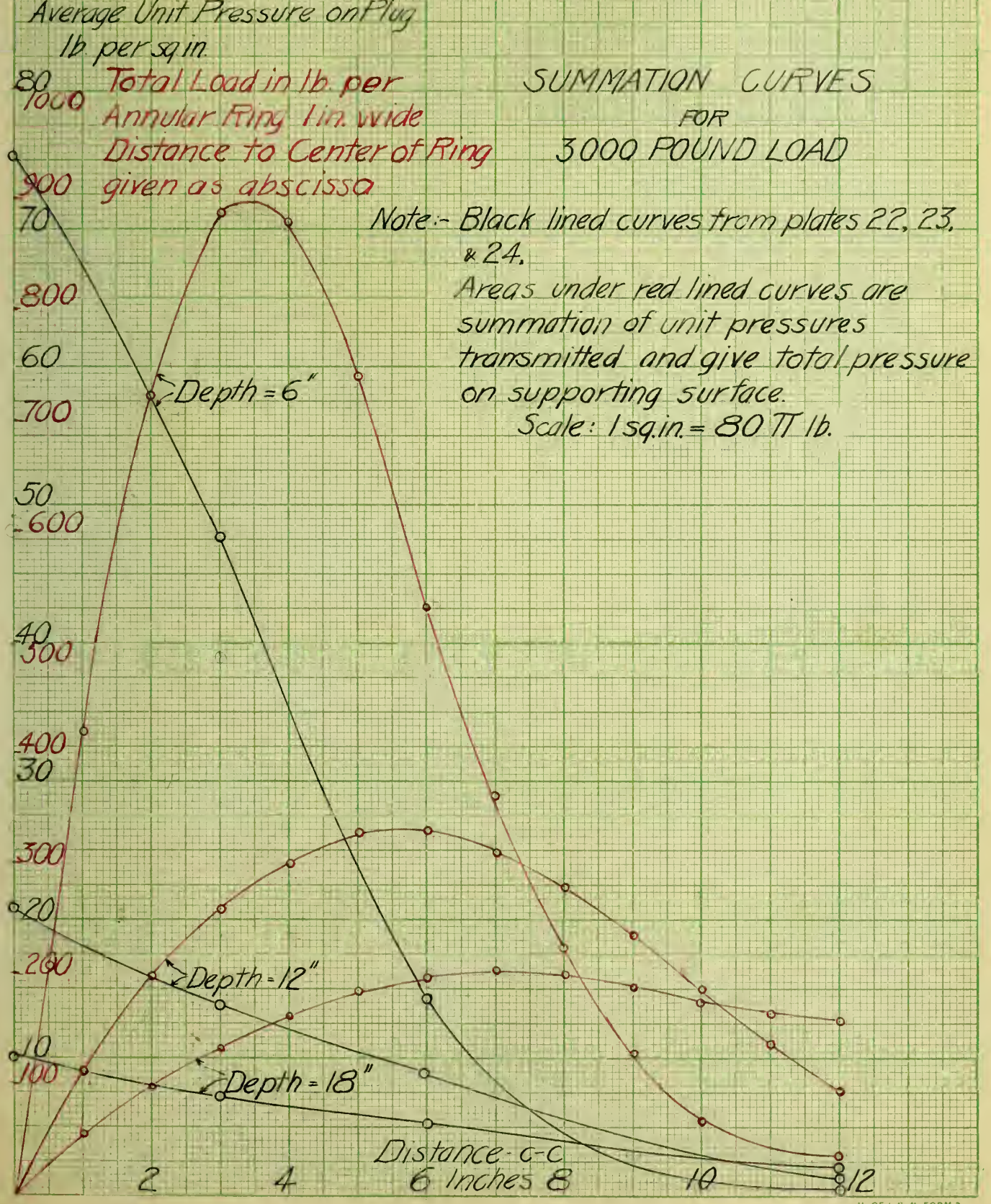
PLATE 24

CURVES SHOWING VARIATION OF INTENSITY OF PRESSURE ON PLUG WITH DISTANCE OF JACK FROM PLUG FOR DIFFERENT LOADS SAND 18" DEEP



U. OF I. S. FORM 7

PLATE 25



SUMMATION CURVES FOR 3000 POUND LOAD

Note:- Black lined curves from plates 22, 23, & 24.

Areas under red lined curves are summation of unit pressures transmitted and give total pressure on supporting surface.

Scale: 1 sq.in. = 80 ℼ lb.

U. OF I. S. 9. FORM 3

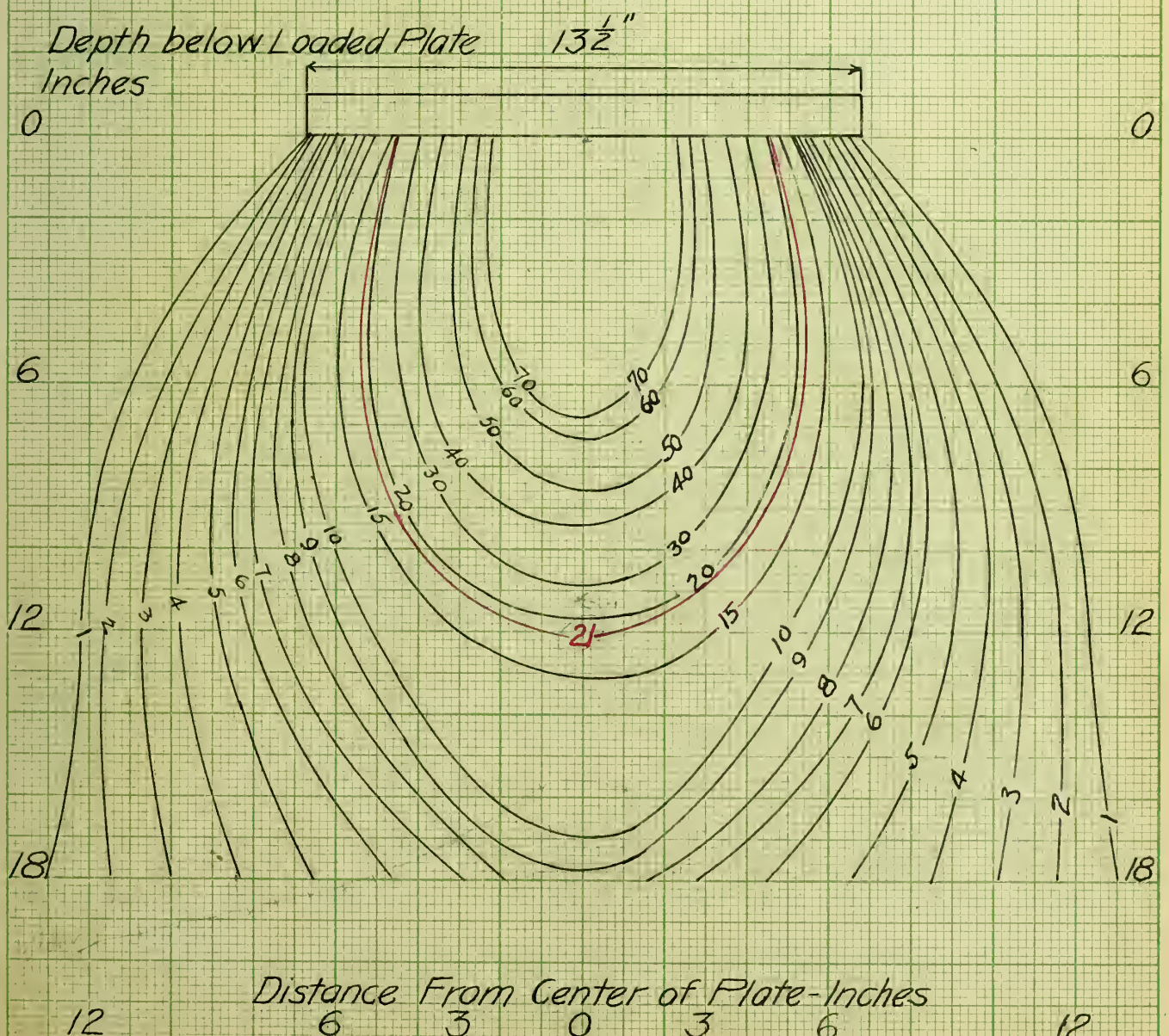
PLATE 26

DIAGRAM SHOWING POSSIBLE DISTRIBUTION OF LINES OF EQUAL VERTICAL UNIT PRESSURE

TOTAL LOAD = 3000 LB.

AVERAGE UNIT LOAD = 21 LB. PER SQ. IN.

Note:- Numbers on lines denote unit pressures in lb. per sq. in. Red line indicates unit pressure equal to average unit pressure on plate.



U OF I. S. FORM 3

than as indicating the exact distribution of forces.

In looking over plates 5 to 21, a considerable difference between the curves for load on and for load off is noticed. In all cases, the load on the plug is higher for load off than for load on. The following explanation is advanced to account for at least part of this difference. When pressure was applied to the plug, the I-beam lever arm was bent somewhat and the plug lowered slightly. As the load was being taken off, the plug would, of course, be pushed upward by the resisting lever arm to cause a greater pressure than would have been the case had there been no motion. The smaller the decreasing load, the greater the percentage of error introduced. The "ratio" curves in plates 15 to 21 indicate that in all probability much of the difference noted between the curves for load on and load off is due to the cause just described. There are probably other factors entering in which cause part of the seeming inconsistency. If the distribution of the lines of pressure through the sand was known with certainty, other causes would no doubt be evident.

Plates 22 to 24 were drawn up for the purpose of making comparisons with similar plates in Mr. Burnell's thesis. The curves show the variation of the unit pressure on the plug with the distance between the center of applied pressure and center line of the plug for a fixed depth of sand and a fixed load on the plate. The curves in plates 22 to 24 have the same general shape as corresponding ones in Mr. Burnell's work, with the exception of the ones for 18 inches of sand, in which case Mr. Burnell's data showed the strong arch action already discussed. The values plotted in plates 22 to 24 do not agree at all closely with corresponding values in Mr. Burnell's plates. In general, Mr. Burnell ob-

tained values for unit pressure on plug for distances of 0 and 6 inches center of plug to center of pressure, which were smaller than corresponding values in this thesis; and larger values for unit pressure on plug for distances of 12 and 18 inches. His work indicated the pressure to be distributed over a much larger area of the supporting surface than the writers' experiments show.

Plate 25 is the result of an attempt to sum up the unit pressures transmitted to the supporting surface. The curves in black are taken from plates 22 to 24 for a total load of 5000 pounds on the plate. The area beneath each curve in red represents to scale the total pressure on the concrete base, and should sum up to 5000 pounds. It is evident that the areas under all the red curves should be equal, as the total load on the plate was 5000 pounds for all cases shown. The points determing the red curves were located by multiplying the unit pressures on the plug shown by the ordinates of the black curves, by their corresponding distances from the center of pressure. The area, then, enclosed beneath the red curves, represents to scale the summation of 2π p x dx where p equals the unit pressure on the supporting surface at a distance x from the center of pressure. According to the calculus, if the expression 2π x dx be integrated between limits, the area of the circle is obtained. If this area be multiplied by unit pressure, the total pressure is obtained. The area beneath each red curve is a graphical integration of the expression 2π p x dx. As shown, each square inch of area represents 80 pounds total pressure, since, for convenience, 2 inches was taken as the unit distance center of plate to center of plug. The area under the red curve for sand 6 inches deep is about 25 1/2 square inches and represents a total load of 5600 pounds. As there was but 5000 pounds

applied, there is a considerable error. The area under each of the other curves is about 11 1/2 square inches, and represents a total load of 2300 pounds. As these areas check quite closely with each other and represent so closely the actual total load applied, they show the data taken for sand 12 and 18 inches deep to be quite accurate. It seems that too high unit pressures were obtained for sand 6 inches deep when the plate was directly over the plug.

Although no attempt was made to determine the amount of horizontal pressure in any of these tests, its effect was noticeable. When the plate was thrust down through sand of considerable depth, the 2 by 12 inch planks 3 1/2 feet long surrounding the concrete base were bowed out by the horizontal pressure of the flowing sand to an extent estimated to be about the same as would be produced by a 175 pound man standing in the middle of a similar plank lying flatwise and supported at its ends. It is suggested that a device be arranged to measure horizontal pressures as well as vertical pressures, should this thesis be taken up in future years.

In examining plate 25, it was noticed that the unit pressures on the supporting surface vary as some function of the depth of sand. To determine if possible this law of variation, logarithmic plottings of unit pressure on the supporting base and corresponding depths of sand were made on plate 27. The curves obtained by these plottings are straight lines for points on the supporting surface directly under the center of applied pressure for depths up to 18 inches and average unit load on the plate of about 21 pounds. These straight-line curves indicate the pressure on the supporting surface to vary with the depth for a constant load on the plate as shown by the formula $p' = kd^n$, where p'

is the unit pressure in pounds per square inch on the supporting surface directly under the center of applied pressure, d is the depth of the sand in inches, and k is a constant depending on the load applied. The exponent n is determined from the slope of the straight-line curves to be 1.84. It is also true that the unit pressure on the supporting surface under the center of applied pressure varies directly with the average unit pressure applied on the plate, so the formula may be expressed

$$p' = \frac{cp}{d^{1.84}}$$ where p is the average unit pressure in pounds per square inch applied on the plate. A substitution of the experimental values for p', p, and d gives a mean value for c of 100.22 and a variation from the mean of 8 percent. As finally determined, the formula

$$p' = \frac{100p}{d^{1.84}}$$

gives values which check closely with the results obtained in these tests for points on the supporting surface directly under the center of applied pressure.

For points on the supporting surface 6 inches from the center of applied pressure the logarithmic plottings show curves which are not straight lines. No attempt has been made to obtain a formula to agree with these results.

Attention is again called to the fact that the sand used in these experiments was very dry.

Table 1

Readings for Calibration of Steel Spring

Total Load on Steel Spring lb.	Deflection of Steel Spring 1/1000's inches
Load increasing (on)	
5040	32.5
10025	63.1
15075	92.0
20015	117.8
25020	141.9
30030	165.0
35025	187.4
39980	210.0
45000	228.4
Load decreasing (off)	
39980	209.7
34780	188.4
29900	166.9
24920	143.9
19990	119.9
15040	94.1
9930	64.3
4845	32.4

Table 2

Plate 8½" dia.

Av. Depth of Sand inches	Av. Defl. of Steel Spring 1/1000's inches	Av. Total Load on Plate lb.	Av. Unit Load Supported lb. per sq. in.	Av. Load Supported Tons per sq. ft.
21.9	2.3	325	5.7	0.4
20.4	3.4	500	8.8	0.6
18.0	5.6	850	14.9	1.1
16.0	8.8	1340	23.6	1.7
14.0	11.25	1730	32.7	2.3
12.0	13.75	2100	37.0	2.7
10.0	16.75	2580	45.0	3.2
8.0	18.10	2800	49.3	3.5
6.0	27.45	4230	74.5	5.4
4.0	50.80	7980	140.5	11.1
3.0	78.00	12330	217.0	15.6

Table 3

Plate 13½" dia.

Av. Depth of Sand inches	Av. Defl. of Steel Spring 1/1000's inches	Av. Total Load on Plate lb.	Av. Unit Load Supported lb. per sq. in.	Av. Load Supported Tons per sq. ft.
18.0	23.5	3600	25.0	1.8
16.0	25.7	4000	27.8	2.0
14.0	29.6	4600	32.0	2.4
12.1	40.0	6200	43.1	3.1
10.0	49.0	7800	54.2	3.9
7.9	63.4	10100	70.0	5.0
6.1	107.0	17950	124.0	8.9
5.0	146.5	26100	181.0	13.0
4.3	179.0	33200	230.0	16.5

Table 4

Plate 21" dia.

Av. depth of Sand inches	Av. Defl. of Steel Spring 1/1000's inches	Av. Total Load on Plate - lb.	Av. Unit Load Supported lb. per sq. in.	Av. Load Supported Tons per sq. ft.
24.6	15.0	2300	6.65	0.5
19.6	30.5	4700	13.6	1.0
15.0	63.9	10100	29.2	2.1
12.0	106.0	17750	51.25	3.7
9.8	160.4	28950	83.6	6.0
9.1	220.2	42500	125.0	9.0

Table 5

Sand 6" deep

Jack 0" from Plug						
Av. Defl. of Steel Spring 1/1000's inches	Actual Load on Plate lb.	Av. Scale Reading lb.	Actual Pres. on Plug lb.	Av. Unit Pres. on Plate lb. per sq. in	Av. Unit Pres. on Plug lb. per sq. in.	Ratio of Av. Plug Pres. to Av. Plate Pres.
Load on.						
0.0	0.0	9.3	0.0	0.0	0.0	
5.7	900	43.0	273.0	6.3	21.6	3.42
10.5	1700	84.5	609.0	11.8	48.3	4.10
15.0	2300	105.0	774.0	16.0	61.3	3.83
20.4	3200	138.5	1045.0	22.2	89.0	3.74
25.8	4000	165.5	1260.0	27.8	100.0	3.59
31.5	4900	194.2	1497.0	34.0	119.0	3.50
35.0	5400	210.5	1630.0	37.5	129.5	3.44
41.0	6400	234.0	1820.0	44.4	144.5	3.26
45.8	7200	258.0	2010.0	50.0	160.0	3.20
59.8	9450	306.0	2405.0	65.6	191.0	2.91
70.3	11200	338.8	2665.0	74.3	212.0	2.85
77.8	12500	373.0	2945.0	86.8	234.0	2.70
89.2	14500	418.2	3315.0	100.8	263.0	2.61
99.0	16400	464.6	3685.0	114.0	292.0	2.56
109.3	18400	518.0	4105.0	128.0	326.0	2.55
121.0	20750	573.0	4565.0	144.0	362.0	2.51

Table 5 Continued

Sand 6" deep

Jack 0" from Plug						
Av. Defl. of Steel Spring 1/1000's inches	Actual Load on Plate lb.	Av. Scale Reading lb.	Actual Pres. on Plug lb.	Av. Unit Pres. on Plate lb. per sq. in.	Av. Unit Pres. on Plug lb. per sq. in.	Ratio of Av. Plug Pres. to Av. Plate Pres.
Load off						
121.8	20900	588.0	4624.0	145.0	367.0	2.53
99.0	16400	565.0	4435.0	114.0	363.0	3.00
82.6	13400	541.0	4245.0	93.0	337.0	3.62
71.6	11500	521.5	4070.0	80.0	323.0	4.05
54.3	8600	489.0	3820.0	59.7	303.0	5.07
51.6	8100	471.0	3670.0	56.2	291.0	5.19
40.6	6300	428.0	3320.0	43.8	263.0	6.00
35.0	5400	406.0	3140.0	37.5	249.0	6.65
30.3	4700	372.0	2870.0	32.6	228.0	7.00
26.0	4050	340.0	2610.0	28.1	207.0	7.36
20.2	3150	286.0	2170.0	21.9	170.0	7.85
10.7	1700	170.0	1235.0	11.8	98.0	8.30
5.6	850	96.8	645.0	5.9	51.3	8.69
0.0	00	16.8	0.0	0.0	0.0	

Table 6

Sand 6" deep.

Jack 3" from Plug.

Av. Defl. of Steel Spring 1/1000's inches.	Actual Load on Plate lb.	Av. Scale Reading lb.	Actual Pres. on Plug lb.	Av. Unit Load on Plate lb. per sq. in.	Av. Unit Pres. on Plug lb. per sq. in.	Ratio of Av. Plug Pres to Av. Plate Pres.
Load on						
0.0	00	0.0	0.0	0.0	0.0	
10.2	1550	39.3	317.8	10.8	25.2	2.310
20.4	3150	76.3	617.0	21.9	49.0	2240
30.2	4650	106.2	859.0	32.3	68.2	2.110
40.0	6200	131.7	1113.0	43.0	88.4	2.055
50.0	7830	156.3	1264.0	54.4	100.5	1.845
60.0	9480	178.5	1442.0	65.8	114.5	1.740
69.8	11120	202.3	1634.0	77.2	129.8	1.680
79.7	12850	224.3	1815.0	89.2	144.0	1.615
89.8	14610	248.3	2010.0	102.0	160.0	1.580
Load off.						
79.1	12500	232.2	1877.0	86.8	149.0	1.720
68.7	10700	223.0	1803.0	74.2	143.2	1.930
59.9	9220	214.8	1737.0	64.0	137.8	2.150
50.2	6910	202.7	1640.0	48.0	130.2	2.710
40.3	6100	186.0	1503.0	42.3	119.3	2.820
30.2	4520	166.0	1342.0	31.4	106.6	3.395
20.4	3050	134.3	1086.0	21.2	86.2	4.060
9.9	1480	78.5	635.0	10.2	50.4	4.930
5.4	800	46.2	373.5	5.6	29.6	5.300
0.0	00	0.0	0.0	0.0	0.0	

Table 7

Sand 6" deep

Jack 6" from Plug

Av. Defl. of Steel Spring 1/1000's inches	Actual Load on Plate lb.	Av. Scale Reading lb.	Actual Pres on Plug lb.	Av. Unit Pres. on Plate lb. per sq. in.	Av. Unit Pres on Plug lb. per sq. in	Ratio of Av. Plug Pres. to Av. Plate Pres.
Load on						
0.0	0.0	4.1	00	0.0	00	
5.0	800	9.8	45.1	5.6	3.6	0.64
10.0	1500	15.7	93.0	10.4	7.4	0.71
16.3	2550	24.2	162.0	17.7	12.8	0.72
25.3	3950	32.8	231.0	27.4	18.3	0.67
35.4	5450	36.7	263.0	37.8	20.9	0.55
40.3	6200	39.8	288.0	43.0	22.9	0.53
45.4	7100	43.2	316.0	49.3	25.1	0.49
50.2	7900	46.8	344.0	54.8	27.3	0.50
60.9	9600	53.0	394.0	66.7	31.3	0.48
70.7	11300	57.5	431.0	78.5	34.2	0.44
81.1	13100	63.2	478.0	91.0	38.0	0.42
91.0	14900	68.4	519.0	103.5	41.2	0.40
100.4	16650	73.7	563.0	115.7	44.7	0.39
109.2	18400	79.1	606.0	127.9	48.1	0.38
Load off						
101.4	16850	83.3	619.0	114.0	43.1	0.43
80.0	12950	74.8	550.0	90.0	43.6	0.48
60.5	9550	62.5	451.0	66.4	35.8	0.54
40.6	6300	49.5	345.0	43.8	27.3	0.62
29.6	4550	42.0	285.0	31.6	22.6	0.72
19.9	3050	34.2	222.0	21.2	17.6	0.83
10.2	1550	26.2	157.0	10.8	12.4	1.15
00	00	6.8	0.0	0.0	0.0	

Table 8

Sand 6" deep.

Jack 12" from Plug.						
Av. Defl. of Steel Spring 1/1000's inches	Actual Load on Plate lb.	Av. Scale Reading lb.	Actual Pres on Plug lb.	Av. Unit Pres on Plate lb. per sq. in.	Av. Unit Pres on Plug lb. per sq. in.	Ratio of Av. Plug Pres. to Av. Plate Pres.
Load on						
0.0	0 0	0.0	0.00	0.00	0.00	
5.8	900	0.25	2.02	6.25	0.16	0.0260
10.7	1650	0.45	3.64	11.5	0.29	0.0250
15.2	2400	0.55	4.45	16.7	0.35	0.0210
21.5	3300	0.55+	4.60	22.9	0.37	0.0155
26.0	4000	0.60	4.85	27.8	0.38	0.0140
31.0	4800	0.70	5.66	33.4	0.45	0.0135
36.5	5625	0.70	5.66	39.1	0.45	0.0115
40.7	6300	0.75	6.06	43.7	0.48	0.0110
46.0	7200	0.80	6.47	50.0	0.51	0.0100
50.5	7950	1.00	8.09	55.2	0.64	0.0115
55.5	8725	1.00	8.09	60.6	0.64	0.0105
61.0	9600	1.00	8.09	66.7	0.64	0.0096
65.4	10400	1.00	8.09	72.2	0.64	0.0089
70.0	11200	1.00	8.09	77.8	0.64	0.0082
76.0	12200	1.00	8.09	84.7	0.64	0.0075
85.0	13800	1.00	8.09	95.6	0.64	0.0067
91.0	14900	1.00	8.09	103.4	0.64	0.0062
99.5	16450	1.05	8.49	114.2	0.67	0.0059
108.0	18100	1.50	1.21	125.8	0.96	0.0075
117.0	19900	1.50	1.21	138.3	0.96	0.0060

Note - No reading taken for "Load off."

Sand 6" deep.

Jack 18" from plug.
No pressure transferred to plug.

Table 9

Sand 12" deep.

Jack 0" from Plug.

Av Defl of Steel Spring 1/000's inches	Actual Load on Plate lb.	Av. Scale Reading lb.	Actual Load on Plug lb.	Av. Unit Pres. on Plate lb. per sq. in.	Av. Unit Pres. on Plug lb. per sq. in.	Ratio of Av Plug Pres to Av. Plate Pres.
Load on						
0.0	00	2.7	0.0	0.0	0.0	
5.1	800	11.5	71.0	5.6	5.7	1.02
10.5	1600	20.9	147.0	11.1	11.7	1.05
15.1	2400	28.8	211.0	16.7	16.8	1.01
20.0	3100	37.8	284.0	21.7	22.6	1.04
25.1	3900	43.8	333.0	27.1	26.5	0.98
30.9	4800	54.3	417.0	33.3	33.1	0.99
35.9	5550	58.6	457.0	38.5	35.9	0.98
39.4	6150	64.7	501.0	42.7	39.8	0.97
45.6	7150	73.2	570.0	49.6	45.3	0.91
Load off						
37.3	5600	65.0	494.0	38.9	39.5	1.01
30.2	4500	60.5	467.0	31.2	36.2	1.16
25.0	3700	56.0	431.0	25.7	33.4	1.30
19.5	2900	50.6	387.0	20.1	29.9	1.49
15.0	2200	45.0	332.0	15.3	26.3	1.72
10.2	1500	36.8	265.0	10.4	21.0	2.02
5.2	750	24.6	166.0	5.2	13.1	2.52
0.0	00	4.0	0.0	0.0	0.0	

Table 10

Sand 12" deep

Jack 3" from Plug.

Av. Defl. of Steel Spring 1/000's inches	Actual Load on Plate lb.	Av. Scale Reading lb.	Actual Pres. on Plug lb.	Av. Unit Pres. on Plate lb. per sq. in.	Av. Unit Pres. on Plug lb. per sq. in.	Ratio of Av. Plug Pres. to Av. Plate Pres.
Load on						
0.0	00	0.0	0.0	0.0	0.0	
5.1	790	4.2	33.9	5.5	2.7	0.490
10.1	1560	10.3	83.2	10.8	6.6	0.610
15.2	2330	17.0	138.0	16.2	11.0	0.680
20.4	3130	22.2	179.5	21.7	14.2	0.655
24.9	3820	26.9	217.5	26.6	17.3	0.650
29.6	4570	31.6	254.5	31.7	20.2	0.638
Load off						
24.9	3700	28.4	229.6	25.7	18.2	0.710
19.4	2890	25.4	205.0	20.1	16.3	0.810
14.9	2200	22.0	178.0	15.3	14.1	0.920
10.4	1550	17.6	142.2	10.8	11.3	1.045
5.0	710	11.5	93.0	4.9	7.4	1.510
0.0	00	0.0	0.0	0.0	0.0	

Table II

Sand 12" deep.

Jack 6" from Plug.

Av. Defl. of Steel Spring 1/1000's inches	Actual Load on Plate lb.	Av. Scale Reading lb.	Actual Load on Plug lb.	Av. Unit Pres. on Plate lb. per sq. ft.	Av. Unit Pres. on Plug lb. per sq. in.	Ratio of Av. Plug Pres. to Av. Plate Pres.
Load on.						
0.0	00	2.5	0.0	0.0	0.0	
5.0	750	6.1	29.2	3.2	2.3	0.435
10.4	1600	10.1	61.1	11.1	4.8	0.425
15.2	2400	12.7	83.0	16.7	6.5	0.390
19.9	3050	16.3	112.0	21.2	8.9	0.420
25.5	3950	18.8	132.0	27.4	10.5	0.380
34.9	4600	21.0	150.0	31.9	11.9	0.370
40.7	6300	27.4	202.0	43.8	15.2	0.350
44.5	6950	29.9	222.0	48.3	17.6	0.360
Load off.						
40.2	6200	28.8	206.0	43.1	16.4	0.380
34.8	5400	26.5	186.0	37.5	14.8	0.390
30.3	4700	25.2	176.0	32.6	14.0	0.430
24.7	3900	23.1	159.0	27.0	12.6	0.470
20.0	3050	21.7	147.0	21.2	11.7	0.550
15.3	2350	19.4	129.0	16.3	10.3	0.630
10.2	1550	16.1	103.0	10.8	8.1	0.750
5.3	850	12.4	71.7	5.9	5.7	0.960
0.0	00	3.5	0.0	0.0	0.0	

Table 12

Sand 12" deep

Jack 12" from Plug

Av. Defl. of Steel Spring 1/1000's inches	Actual Load on Plate lb.	Av. Scale Reading lb.	Actual Load on Plug lb.	Av. Unit Pres. on Plate lb. per sq. in	Av. Unit Pres. on Plug lb. per sq. in.	Ratio of Av. Plug Pres. to Av. Plate Pres.
Load on						
0.0	0 0	0.00	0.00	0.00	0.00	
5.0	750	0.50	4.04	5.23	0.32	0.061
10.3	1625	0.89	7.20	10.70	0.57	0.053
15.2	2360	1.38	11.15	15.76	0.89	0.056
20.2	3140	1.71	13.81	21.10	1.10	0.052
25.2	3900	2.12	17.15	26.50	1.36	0.051
30.4	4720	2.50	20.20	31.70	1.61	0.051
35.4	5460	3.00	24.25	37.30	1.93	0.051
39.9	6180	3.45	27.90	42.10	2.22	0.053
44.0	6900	3.75	30.30	46.75	2.41	0.052
Load off						
36.1	5450	3.25	26.30	37.90	2.09	0.055
30.0	4500	2.83	22.90	31.20	1.83	0.058
25.0	3720	2.40	19.40	25.80	1.54	0.060
19.9	2950	2.00	16.20	20.50	1.28	0.062
14.7	2200	1.50	12.12	15.30	0.96	0.063
10.3	1550	1.25	10.10	10.75	0.68	0.063
5.2	770	0.64	5.27	5.35	0.41	0.076
0.0	00	0.0	0.0	0.0	0.00	

Sand 12" deep

Jack 18" from Plug

No pressure transmitted to plug.

Table 13

Sand 18" deep

Jack 0" from Plug						
Av. Defl. of Steel Spring 1/1000's inches	Actual Load on Plate lb.	Av. Scale Reading lb.	Actual Pres. on Plug lb.	Av. Unit Pres. on Plate lb. per sq in.	Av. Unit Pres. on Plug lb. per sq in.	Ratio of Av. Plug Pres. to Av. Plate Pres.
Load on						
0.0	0	4.1	0.0	0.0	0.0	
5.1	770	7.2	25.1	5.6	2.0	0.36
10.3	1600	11.1	56.7	11.1	4.5	0.41
15.1	2400	14.9	87.4	16.7	7.3	0.44
19.8	3050	17.6	109.0	21.2	8.7	0.41
24.6	3800	20.8	135.0	26.4	10.7	0.40
Load off						
24.1	3600	20.4	132.0	25.0	10.5	0.42
20.1	3000	19.5	125.0	20.8	9.9	0.48
14.9	2200	17.5	108.4	15.3	8.6	0.56
10.0	1500	14.8	86.9	10.4	6.9	0.66
5.2	750	10.8	54.2	5.2	4.3	0.83
0.0	00	4.1	0.0	0.0	0.0	

Table 14

Sand 18" deep

Jack 3" from Plug.						
Av. Defl of Steel Spring 1000's inches.	Actual Load on Plate lb.	Av. Scale Reading lb.	Actual Pres. on Plug lb.	Av. Unit Pres. on Plate lb. per sq. in.	Av. Unit Pres. on Plug lb. per sq. in.	Ratio of Av. Plug Pres. to Av. Plate Pres.
Load on						
0.0	00	0.0	0.0	0.0	0.0	
5.4	825	2.1	17.0	5.7	1.35	0.237
10.0	1530	5.0	40.4	10.6	3.2	0.302
14.8	2250	7.5	60.6	15.6	4.8	0.308
18.3	2850	9.2	74.4	19.8	5.9	0.298
Load off						
15.0	2230	8.1	65.5	15.5	5.2	0.335
9.9	1430	6.2	50.2	9.9	4.0	0.404
5.1	740	3.9	31.5	5.1	2.5	0.490
0.0	00	0.0	0.0	0.0	0.0	

Table 15

Sand 18" deep.

Jack 6" from Plug.						
Av. Defl. of Steel Spring 1/1000's inches	Actual Load on Plate lb.	Av. Scale Reading lb.	Actual Pres. on Plug lb.	Av. Unit Pres. on Plate lb. per sq. in.	Av. Unit Pres. on Plug lb. per sq. in.	Ratio of Av. Plug Pres. to Av. Plate Pres.
Load on.						
0.0	00	0.8	0.0	0.0	0.00	
5.1	750	2.5	13.7	5.2	1.12	0.210
10.2	1600	4.6	30.7	11.1	2.47	0.220
15.0	2300	6.9	49.4	16.0	3.97	0.248
19.7	3000	8.7	63.9	20.8	5.12	0.246
24.3	3600	10.5	77.5	25.0	6.17	0.246
Load off.						
20.5	3050	9.8	72.7	21.2	5.82	0.280
15.1	2250	8.6	63.0	15.6	5.02	0.320
10.0	1500	6.7	47.7	10.4	3.82	0.370
5.2	800	4.9	33.1	5.6	2.67	0.48
0.0	00	0.8	0.0	0.0	0.00	

Table 16

Sand 18" deep.

Jack 12" from Plug.						
Av. Defl. of Steel Spring 1/1000's inches	Actual Load on Plate lb.	Av. Scale Reading lb.	Actual Pres. on Plug lb.	Av. Unit Pres. on Plate lb. per sq. in.	Av. Unit Pres. on Plug lb. per sq. in.	Ratio of Av. Plug Pres. to Av. Plate Pres.
Load on						
0.0	00	0.00	0.00	0.00	0.00	
5.4	850	0.87	7.04	5.60	0.56	0.100
10.1	1600	1.37	11.80	11.10	0.88	0.080
15.2	2340	2.00	16.18	16.25	1.29	0.0795
20.0	3100	2.75	22.20	21.50	1.77	0.080
Load off						
15.0	2220	2.60	21.20	15.40	1.69	0.110
10.0	1480	1.89	15.10	10.28	1.20	0.117
5.3	760	1.12	9.07	5.28	0.73	0.137
0.0	00	0.00	0.00	0.00	0.00	

Sand 18" deep.

Jack 18" from Plug.
The maximum pressure transmitted to plug was barely perceptible.

PLATE 27

LOGARITHMIC PLOTTINGS OF THE DEPTH OF SAND AND UNIT PRESSURE ON SUPPORTING SURFACE FOR VARIOUS APPLIED UNIT PRESSURES AND DISTANCES FROM CENTER OF PRESSURE

Average Unit Pressure on Supporting Surface lb. per sq. in.

20.8 lb. per sq. in.

20.8 lb. per sq. in.

13.9 lb. per sq. in.

6.95 lb. per sq. in.

20.8 lb. per sq. in.

13.9 lb. per sq. in.

6.95 lb. per sq. in.

LEGEND

0 inches from center of pressure to center of supporting surface

3 inches center to center

6 inches center to center

Depth of Sand - Inches

COPYRIGHT 1908. J. NORMAN JENSEN, CIVIL ENGINEER, CHICAGO, ILL., U. S. A.

IV. Conclusions.

1. The maximum load sustained by a bed of sand diminishes as the depth of sand increases.

2. With the loaded areas used, the maximum load sustained increases slowly as the depth decreases from 18 inches to about 10 inches, and much more rapidly below that depth.

3. It is probable that for depths greater than about 24 inches the maximum load sustained would decrease so slowly with increasing depth that it would be practically constant, for conditions similar to those under which these tests were performed.

4. The maximum unit load sustained by a bed of dry sand increases with the area loaded.

5. The experiments show that the pressures transmitted through a bed of dry sand are distributed over areas of the supporting surface varying from about 4 1/2 times the loaded area for a depth of 6 inches to about 9 1/2 times the loaded area for a depth of 18 inches.

6. The unit pressure on the supporting surface is a maximum at the center of the applied load; it decreases very rapidly with the distance from this point up to a distance equal to about a mean between the diameter of the plate and the depth of the sand. Beyond this point the decrease of the unit pressure is not so rapid.

7. As the unit pressure applied increases the area of the supporting surface over which the pressure is distributed increases.

8. For points directly below the center of applied pressure the decrease of the unit pressure transmitted with increasing depth of sand varies inversely with some power of the depth. This power is 1.84 for

these tests. For the 15 1/2 inch plate and for depths of sand up to 18 inches the formula

$$p' = \frac{100p}{d^{1.84}}$$

agrees with the results of the experiments; p, p', and d being respectively the average unit pressure in pounds per square inch applied on the plate, the unit pressure in pounds per square inch on the supporting surface directly below the center of applied pressure, and the depth of sand in inches.

9. No arch action is shown ny these experiments for depths of dry sand up to 18 inches.

10. The apparatus is a decided improvement upon the simpler and less rigid apparatus used by Mr. Burnell in his thesis on the same subject. It is hoped by the writers that the apparatus may be used in the following years to make tests upon wet sand, crushed stone, gravel, and earth.

UNIVERSITY OF ILLINOIS-URBANA
3 0112 086857908